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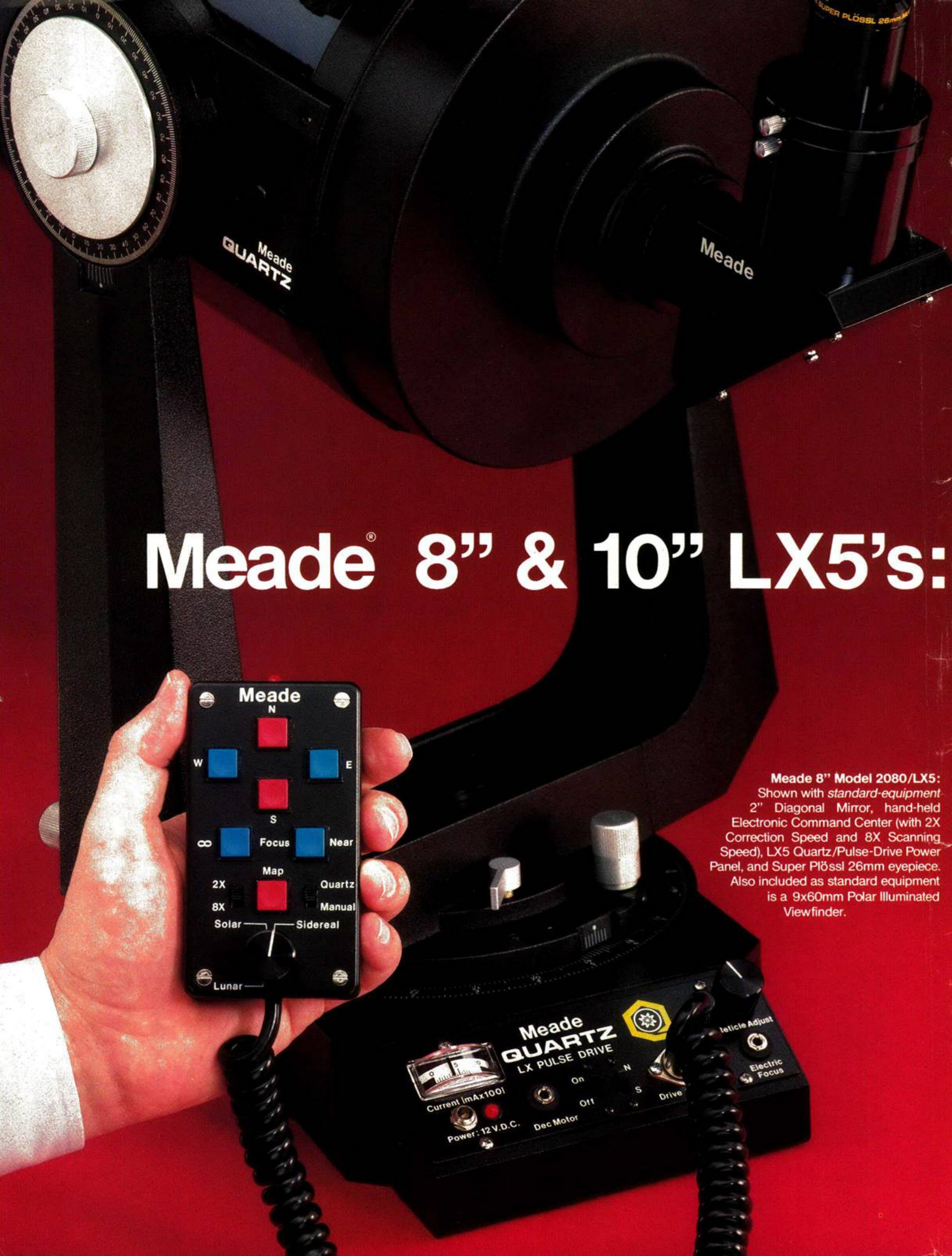
The Life Cycle of Planetary Rings

Exploring the Milky Way

Special Report: Summer Amateur Meetings

ICD# 08070

Probing Saturn's Rings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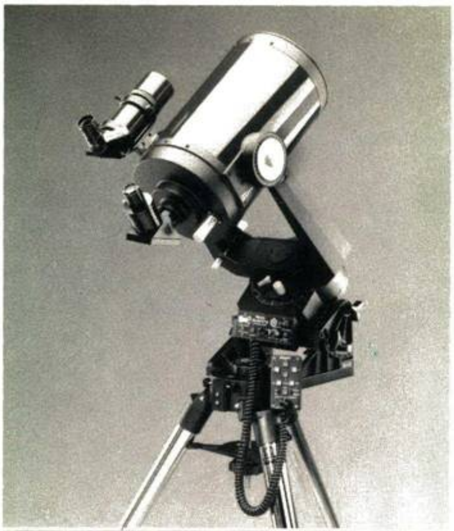

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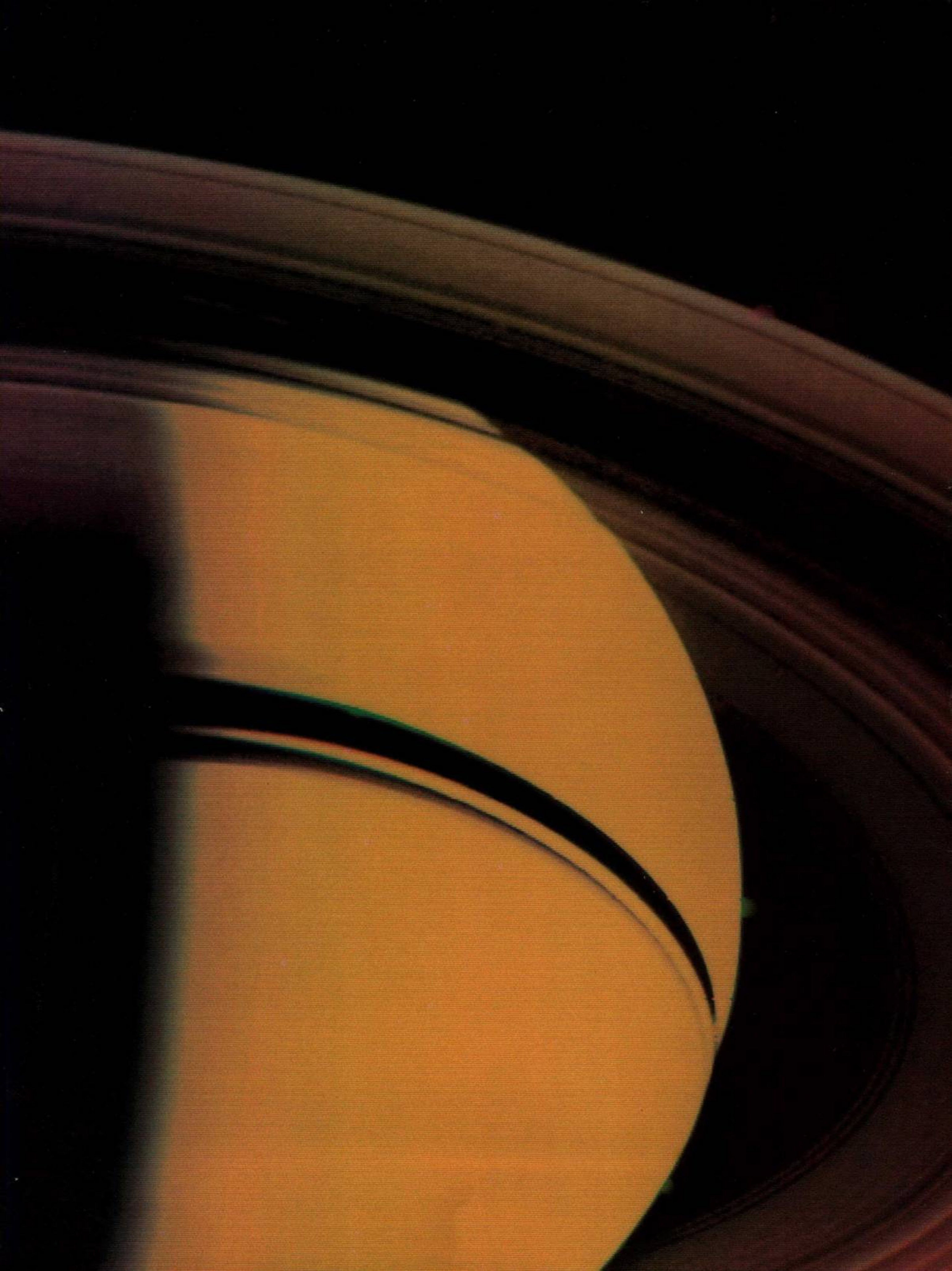

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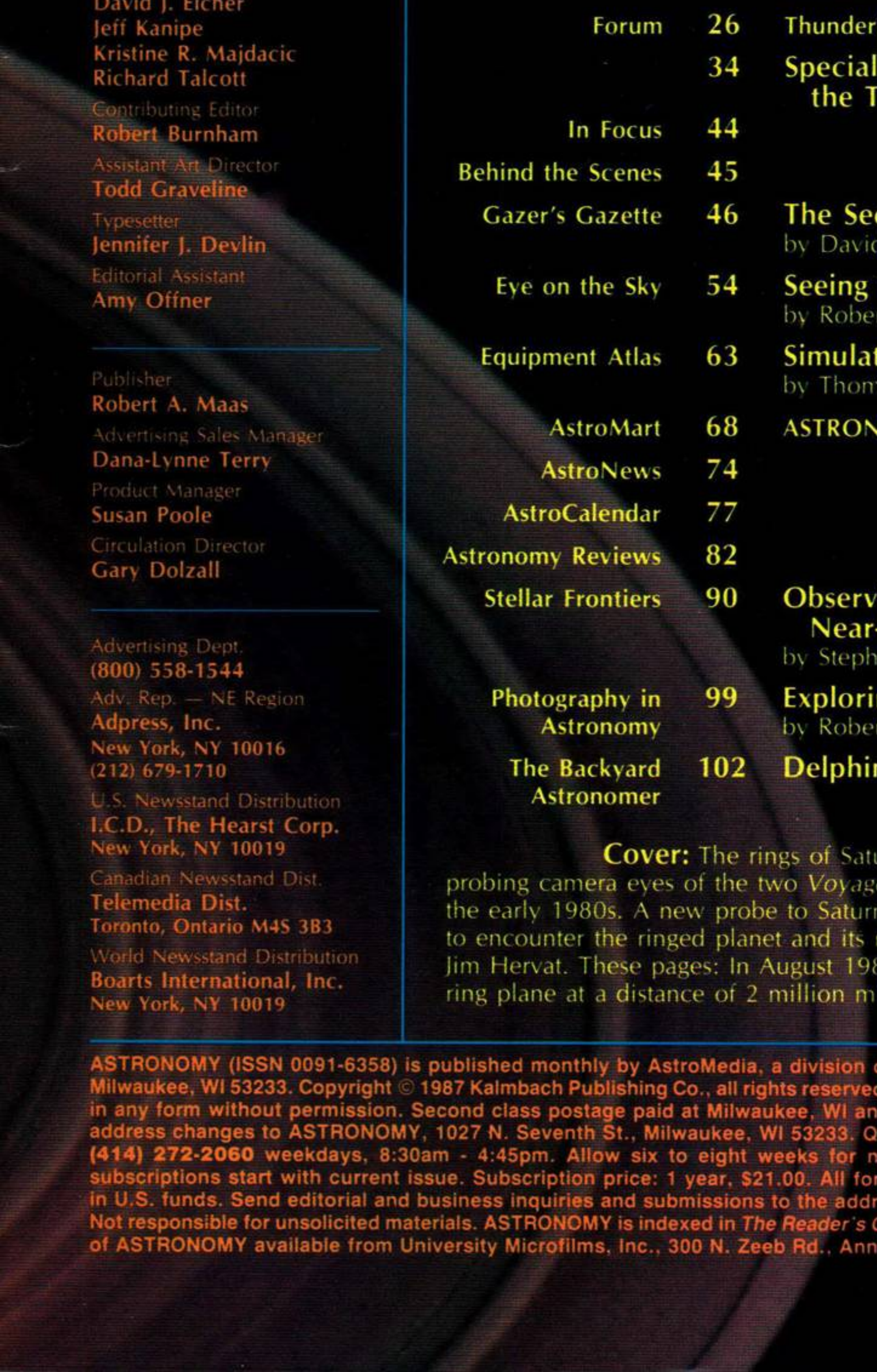

Cover: The rings of Saturn revealed an intricate structure to the probing camera eyes of the two *Voyager* spacecraft that flew past the planet in the early 1980s. A new probe to Saturn — the *Cassini* mission — is scheduled to encounter the ringed planet and its moon, Titan, in the 1990s. Painting by Jim Hervat. These pages: In August 1981, *Voyager 2* photographed Saturn's ring plane at a distance of 2 million miles. NASA photo.

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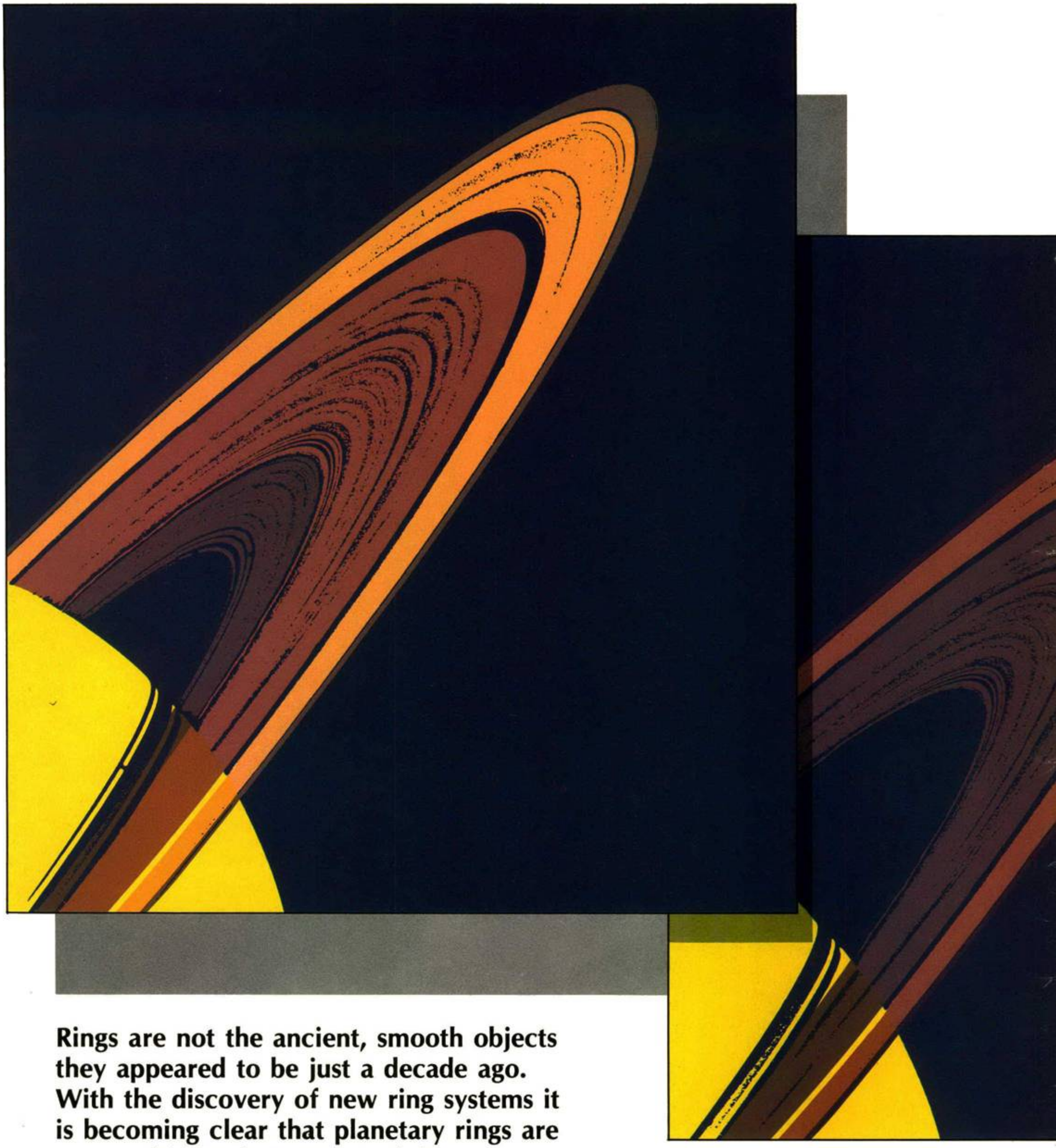
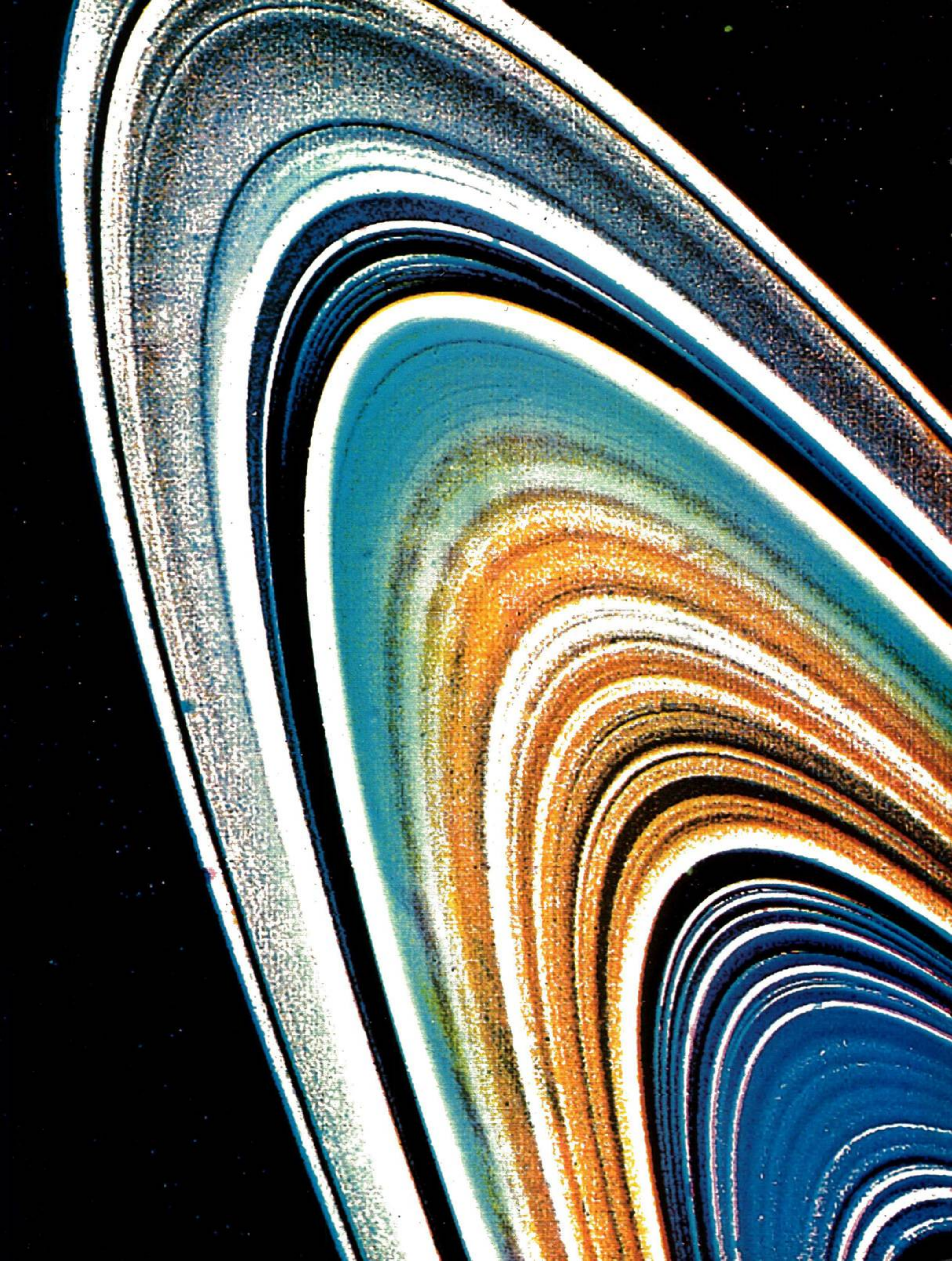
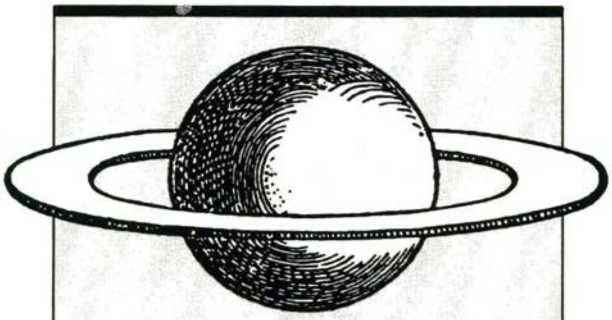


Rings are not the ancient, smooth objects they appeared to be just a decade ago. With the discovery of new ring systems it is becoming clear that planetary rings are young objects that grow and decay.

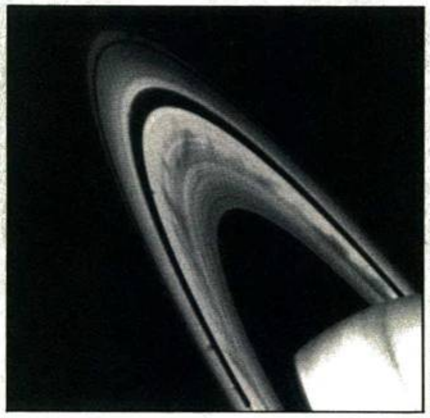
by Larry W. Esposito

The Changing Shape of Planetary Rings





NASA photo (*Voyager 1*)



NASA photo (*Voyager 2*)

Our understanding of Saturn's ring system has changed from the solid-ring concept of Christiaan Huygens (top), to a smooth, three-part ring (middle), to a complex system of rings within rings (opposite page) and dark spokes (above).

As far as anyone knew in 1610, the only shape celestial bodies came in was a sphere. So when Galileo first looked at Saturn through a telescope, he thought he saw two large moons on opposite sides of the planet.

A ring-shaped object around a planet was inconceivable.

One generation later, Dutch astronomer Christiaan Huygens could conceive of a planetary ring. Saturn's ring was a rigid, relatively thick object that revolved around the planet.

A ring was a solid object.

A century ago Saturn's ring system was the paradigm of planetary rings. Rings were wide sheets of particles orbiting in a collisionless equilibrium. Rings were as old as the solar system.

Rings were forever.

Today a menagerie of rings is known to exist around several planets: narrow bands, faint dust rings, arc-shaped partial rings. Rings are exotic shapes influenced by dynamic processes.

Rings are young and continually changing.

As our understanding of these beautiful and mysterious objects has evolved over the last three centuries, planetary rings have revealed more and more fascinating personalities. What was once a single, rigid disk around a single planet is now a diverse family of objects influenced by complex physical processes. With the wealth of new information now available, astronomers have discovered that planetary rings are evolving, sometimes rapidly, through a life cycle of creation and decay.

The major source of this new data is the remarkable achievements of the United States' *Voyager* mission to the outer planets. A pair of spacecraft launched in 1977 have observed at close range the planets Jupiter, Saturn, and Uranus. In 1989 when *Voyager 2* encounters Neptune, a single spacecraft will have observed all four of the solar system's giant planets.

Voyager has discovered new rings and has shown us amazing new details in rings we already know about. Because similar experiments are carried out at each planet, the *Voyager* results highlight the similarities and differences of the planets' ring systems. This general knowledge may be even more important than the multitude of new details learned about each ring.

Our understanding of planetary rings was limited in the pre-*Voyager* era by astronomers' ability to observe planets from Earth. Before 1977 Saturn's ring system was the only one we knew of. Consequently, at that time theories for ring formation and evolution were based on the uniqueness of the Saturnian system.

Saturn's rings evolved from Huygens' original view of a single ring into a system of rings in 1676, when Giovanni Cassini discovered the gap between the two brightest rings that now bears his name. In the nineteenth century a third translucent inner ring was discovered. The three rings were named A, B, and C: ring A is the outermost, ring B is the "brightest," and ring C is the innermost translucent "crepe" ring.

As far as ground-based observations could determine, a planetary ring was a wide, smooth sheet, azimuthally symmetric and unchanging. Saturn's B ring is over 15,000 miles wide; the Earth would easily fit into the 8,500-mile-wide A ring. The rings were composed of broad, smooth elements that had long ago achieved a collision-

NASA photo (*Voyager 2*)

less equilibrium.

Astronomers assumed the rings were remnants left over from the creation of the solar system. As in the asteroid belt, tides had kept this material from coalescing into satellites near Saturn. Slow evolutionary processes like light drag and meteorite grinding could gradually change the appearance of the rings, but not significantly. Fine-scale structure was not easily seen from Earth and was very controversial. Astronomers disagreed on the number of gaps in the rings and whether there were regions of varying material in the ring.

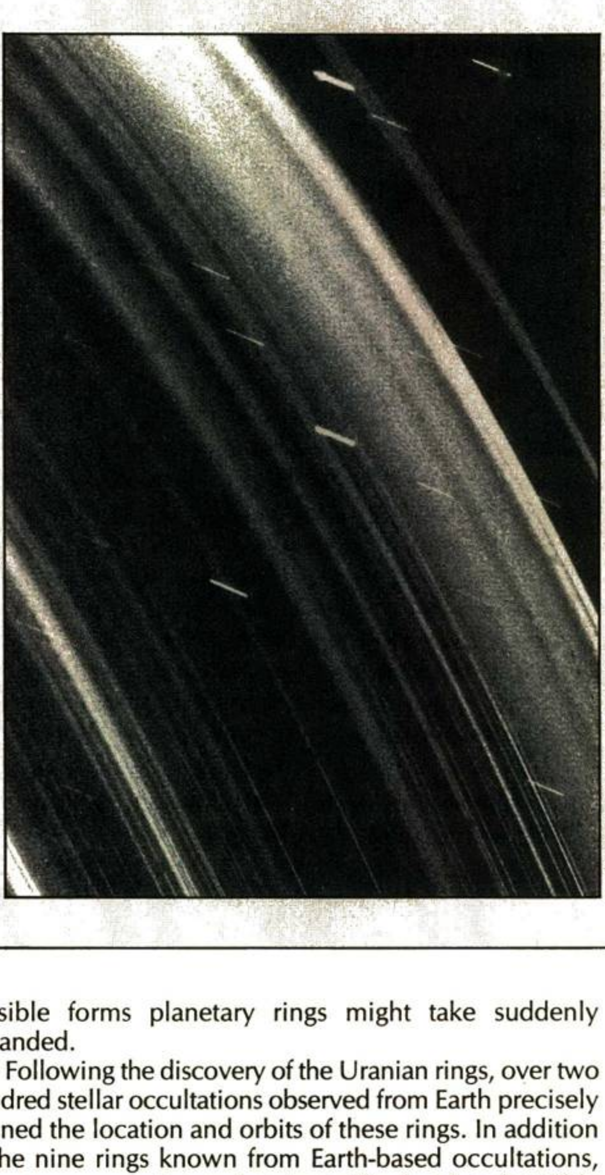
This classical description of planetary rings was shattered by the close-up views the two *Voyager* spacecraft provided and by the discovery of new ring systems around other outer planets. Along with broad rings, we now see very narrow rings, noncircular rings, kinky rings, and dusty rings. No ring appears smooth: the closer we look, the more structure we see. The dynamic — perhaps even transitory — phenomena observed in the ring structure and the short lifetimes of ring particles mean the rings are changing. The rings may well be remnants, but now the question is, of what?

This process of redefining planetary rings began with the discovery of a very un-Saturnlike ring system around Uranus in 1977. Nine narrow rings were inadvertently detected from Earth by astronomers who were using a new method of stellar occultation developed in the 1970s to study the atmospheres of planets. The technique is observing a star with a telescope as a planet passes between the star and Earth. With this method, features as small as several miles across can be detected.

In March 1977 astronomers observing the occultation of a star by Uranus were careful to start their observations well ahead of the predicted time of encounter and continue them for as long as possible afterward. They were surprised to find that short blockages of starlight occurred before Uranus passed in front of the star and after the occultation ended.

At first these brief occultations were attributed to a belt of moons orbiting the planet. The possibility of rings was initially rejected because the rings would need to be very narrow, much narrower than Saturn's rings. However, within days comparisons showed that each blockage on one side of Uranus was matched by another on the other side. This immediately led to the conclusion that a new set of rings had been discovered. Our view of the possible forms planetary rings might take suddenly expanded.

There Are Rings and Then There Are Rings

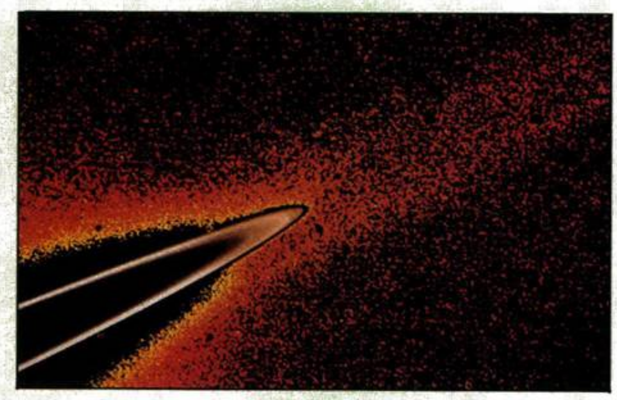


NASA photo (*Voyager 2*)

Following the discovery of the Uranian rings, over two hundred stellar occultations observed from Earth precisely defined the location and orbits of these rings. In addition to the nine rings known from Earth-based occultations, one new narrow ring and perhaps fifty dust bands visible only from the unlit side of Uranus were discovered by *Voyager 2* in January 1986. The newly discovered rings contain small particles with very short lifespans because of drag from Uranus' extended atmosphere.

The ten narrow Uranian rings range in size from about 25 miles to less than 1 mile across. *Voyager* photographs show the rings to be charcoal black. Several of the rings are noncircular and some are inclined to the orbital plane of the planet. All are probably made of carbon-rich rocky particles.

A third ring system — different from both the Uranian and Saturnian systems — was discovered in March 1979 when *Voyager 1* reached Jupiter, the first of the



Voyager 2 image, courtesy Joseph A. Burns

In just the last decade a menagerie of rings quite unlike Saturn's broad ring system has been discovered around Jupiter, Uranus, and Neptune. A single main ring with a doughnut-shaped halo of particles inside it and a faint plane of material outside it orbits Jupiter (above). Several partial rings — ring arcs — have been detected around Neptune. Multiple dust rings (left) were found among the ten narrow Uranian rings.

These diverse rings, so different in size and shape, may share a common evolutionary cycle. The varied ring shapes we see now may be different stages in a common life cycle of creation, development, and decay.

spacecraft's planetary destinations. In 1972 the *Pioneer 10* spacecraft had detected a region near Jupiter's equator where charged particles circling the planet were surprisingly absent. *Voyager 1* pointed its cameras at the area in an attempt to confirm the existence of a suspected ring. (That particular picture was taken despite strong arguments that the area would be empty, and thus taking a picture was a waste of time. After all, anything resembling Saturn's rings would already have been discovered.) The picture confirmed the existence of a highly transparent, flattened, dusty ring system. At this time three of the giant planets had revealed ring systems, all different from one another.

When *Voyager 2* passed Jupiter four months later, the spacecraft was reprogrammed to take improved pictures of the Jovian ring system from behind the planet, facing the Sun. These backlit pictures revealed three different elements of the Jovian ring system. The main ring was approximately 4,000 miles wide and was made up of very small particles, typically 1/10,000th of an inch across. A diffuse "gossamer" ring stretches away from the main ring. The faint "halo," a doughnut-shaped area 12,000 miles in diameter located just inside the main ring, circles the planet far above the Jovian cloud tops.

Voyager 1's next stop — Saturn — revealed that Saturn's quintessential ring system was anything but the smooth, featureless phenomenon astronomers had seen from Earth. New rings around Saturn were found, including my own discovery of Saturn's F ring in 1979. The *Voyager* observations made in November 1980 and August 1981 included images of the entire ring system, closeups of rings and moons, eccentric rings, kinky rings, and other exotic sights.

In addition to the cameras, several *Voyager* instruments observed stellar and radio occultations by the rings. Although occultation observations don't sample all longitudes in the rings, they can show details in the rings one hundred times smaller than those visible to the cameras. A radio occultation (the source of radiation is the spacecraft transmitter, not a star) directly measures the sizes of ring particles.

The rings of Saturn now run from A to G, but somehow the original orderliness of the nomenclature has been lost. The *Voyager* images show the classic A, B, and C rings; the braided F ring and the narrow G ring, discovered by *Pioneer* beyond the A ring; and the innermost D ring and the outermost E ring, which had been suspected from ground-based observations.

Saturn's rings showed structure at every level from 100 yards to 10,000 miles. High-resolution images revealed several kinds of periodic wavelike motions in the rings. Bending waves, seen as ripples in the ring surface, moved particles vertically in the ring plane; density waves increased and decreased the number of particles in a certain area; and edge waves created scallop-shaped wiggles along the ring boundaries.

From the *Voyager* wave observations we can determine several important ring properties. The combined mass of Saturn's rings is comparable to that of Saturn's small moon Mimas, which is about 200 miles across. Saturn's rings aren't very thick, only about 100 feet in the main rings, though the rings are much bigger than an individual particle. The individual particles are made mostly of ice and range in size from golfball- to house-sized boulders. Some dust is found in the system too.

The discovery of new ring types and systems did not stop when *Voyager* left Saturn. While *Voyager 2* was en route to a 1986 encounter with Uranus, ground-based astronomers discovered a ring system around Neptune unlike any of the previous three systems. The Neptunian rings — if that is the correct word for these objects — only partially circle the planet. While multiple stellar occultation observations have detected the existence of these rings on one side of the planet, another location partway around the planet at the same distance is vacant. Current occultation data reveal at least two and possibly as many as four "ring arcs" orbiting at different distances from the planet.

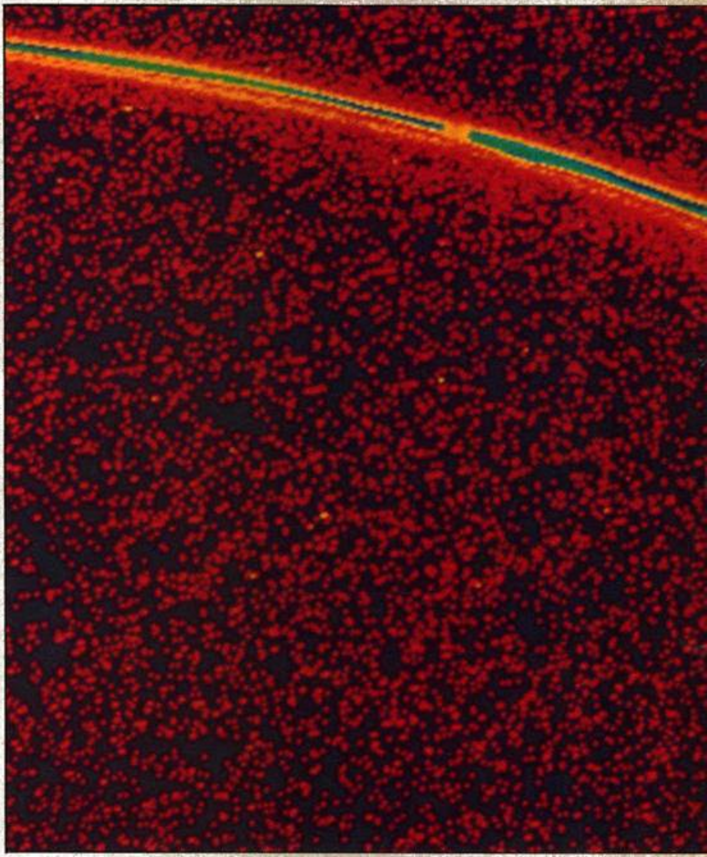
This situation seems extremely transitory, although the right arrangement of small, unseen moons near Neptune could possibly confine these ring arcs. When *Voyager* arrives at Neptune in 1989, it will attempt to image these arcs and any moons near them and carry out occultation experiments that could discern the detailed structure of the ring material.

With three new ring systems and a wealth of new data to ponder, astronomers have come to know planetary rings a lot better in the last decade. Building on our pre-spacecraft era understanding of Saturn's rings, astronomers now see planetary rings as actively evolving systems influenced by many dynamic processes. This new understanding has led to new ideas about how rings work.

The rings we see are made of myriad small particles, each particle a tiny moon of the planet on its own orbit. For most rings this orbit is nearly circular and lies almost exactly above the planet's equator. Shortly after a ring forms, the ring particle orbits may be noncircular and tilted to the planet's equator. At that moment the "ring" would have appeared to be a cloud or perhaps a doughnut surrounding the planet. However, collisions between the ring particles quickly flatten the ring and circularize the orbits. The ring then takes on the form we now see: a flat annulus surrounding the planet's equatorial plane.

Inside the planetary rings several important ongoing processes take place: particles collide, the rings spread, satellites create waves and gaps. The particles in planetary rings are not a perfect society. Their orbits are not exactly alike, so collisions occur frequently (more than once per orbit in parts of Saturn's rings). Some of these collisions break the particles or displace dust lying on the particle surface. After other collisions the particles may stick together.

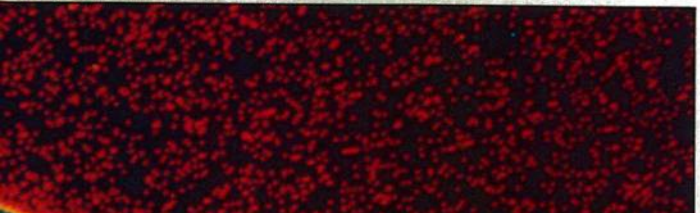
Ring Today, Moons Tomorrow: Saturn's F Ring



When astronomers get their next close-up view of Saturn, which will be through the Space Telescope, they may find one ring missing. The thin F ring that skirts the outside edge of Saturn's broad ring system may have collapsed from a ring into a jumble of small moons.

"The F ring may be a temporary phenomenon," says astronomer Joseph Burns of Cornell University, who with Jeffrey Cuzzi of NASA's Ames Research Center has re-examined spacecraft date on the F ring and proposed that the ring is evolving rapidly — on a time scale measurable in decades.

The evidence shows that the F ring is not a stable system, Burns asserts. The two small moons credited with "shepherding" the particles into a narrow, steady ring are not in the right positions to confine the ring. The F ring is also unstable because it lies near the boundary



Voyager 1 image, color processing by Mark Showalter

between the regions where particles can and cannot accrete to form a moon.

Burns and Cuzzi hypothesize that a band of kilometer-size moonlets extends over a 2,000-kilometer-wide swath surrounding the F ring. In this region they have detected localized clouds of faint material, which they propose are created when moonlets collide with one another and lose surface debris. These particles eventually run into other moonlets and are deposited there.

In this view the F ring is merely the largest of these clouds — the result of a collision between two large moonlets. Over the course of a few decades the particles will collide with nearby moonlets and be lost to their surfaces.

When astronomers look at Saturn again, there may be two or three F rings or only a scattering of tiny moons, depending on the recent history of the ring particles.

Every collision changes the orbit as well as the spin and orientation of the particles. The particles naturally achieve some equilibrium distribution in size from small to large after existing in this environment for a long time. This size distribution is seen in Saturn's rings and is less well known for the rings of Jupiter and Uranus.

Clearly, after ages of collisions the ring particles are battered and eroded. In some parts of each of the ring systems we also observe dust: small particles with short lifetimes that were recently chipped or knocked off larger ring particles.

The collisions have a second effect: they redistribute momentum among the colliding particles. That is, after a collision the formerly slower moving particle tends to move faster, and vice versa. Because each particle is an individual satellite in orbit, its velocity determines its altitude of orbit. (Remember, the shuttle astronauts have to fire their thruster rockets to change orbit.) This means the redistribution of momentum tends to spread the ring particle orbits in altitude, and the ring spreads. Somehow narrow rings have escaped this fate. Either they are young and have not had time to spread, or they are confined by some force.

One of the forces that may confine rings is the gravitational pulls from the satellites of the planet. As first suggested by Peter Goldreich of Caltech and Scott Tremaine of the University of Toronto, a small moon may serve to confine a ring by a mechanism called "shepherding." The shepherd moons keep the particles in place the way a shepherd confines his flock. As an errant particle attempts to leave the ring, the particle's orbit is altered by the nearby moon and the particle is sent back in toward the ring.

The *Voyager* discoveries have included a bevy of small moons near the giant planets, quite close and occasionally among the rings. These small satellites close to rings are now called "ringmoons." These ringmoons can exert a strong influence on the many particles comprising the rings.

The shepherding mechanism is just one example of the influence satellites can have on rings. Planetary rings receive gravitational attraction from ringmoons. Most of these gravitational pulls come to nothing, occurring at one time in a particle's orbit and at another in the next. Some ring particles, however, orbit at a distance where the moon's pull repeatedly occurs at the same phase of the particle's orbit. These particles have an orbital period that is approximately some simple fraction (like 1/2, 1/3, 2/3, 3/5) of the orbital period of the moon. Such particles are called resonant, and the distances in the rings where this phenomenon occurs are called resonances.

Resonances commonly occur on Earth when someone is tuning a transistor radio. At some locations on the dial our radio resonates with the signal and we hear music or Dr. Ruth. In between we just hear static. At some distances from the planet the rings are tuned to the frequency that the satellite passes, so edges, waves, and other phenomena occur at these locations. At the other locations the moons only contribute static.

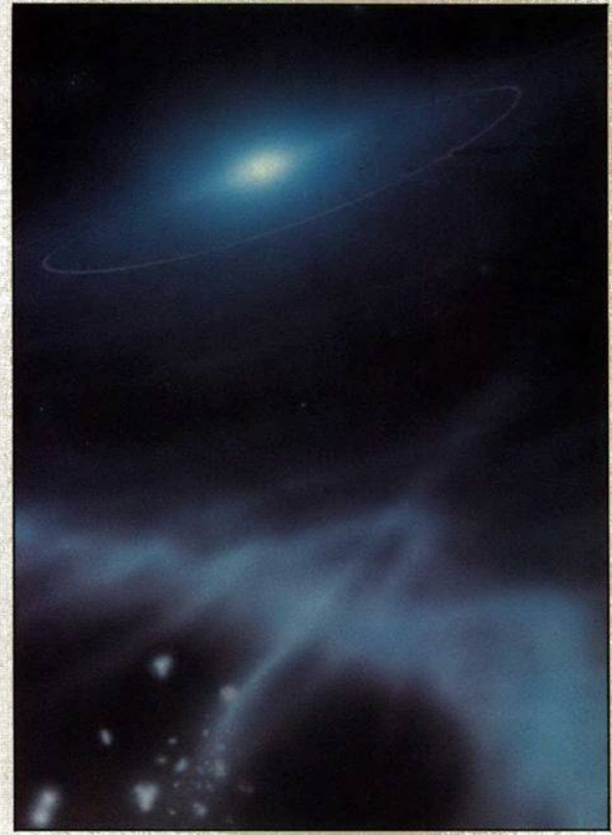
The recognition of these phenomena has given us a more complicated view of how rings work. Particles continually collide and break or stick. The ring particles have a range of sizes established by this collision equilibrium. Occasionally a collision releases a burst of very small particles that fills the rings with dust. The rings of a planet tend to spread, but the common occurrence of narrow rings shows that this tendency is halted by other processes. Any smooth sheet of ring particles is broken and perturbed by satellite resonances.

The rings we have seen through *Voyager*'s eyes, the rings these dynamic processes are at work upon, could not have lasted the billions of years since the formation of the planets themselves. With the *Voyager* data in hand we can describe the details of the ring structure, seek evidence for the slow evolutionary processes, and determine the age of the rings.

Indications that there were difficulties with the old-ring concept came from the discovery of "microstructure" in Saturn's rings. At high resolution the rings show considerable structure: they break into ringlets, and the ringlets break into smaller ringlets. With the *Voyager* studies astronomers could see features as small as 100 yards wide in the rings. Very little of this structure can be associated with the perturbing influences of moons.

In Saturn's B ring few resonances exist, and this microstructure shows no preference for those locations. Furthermore, numerical models simulating the collisional evolution of rings show that these ring features resemble those of relatively young rings, not those of great age. This suggests that the rings are out of equilibrium. Either processes we aren't aware of are acting on the rings, or Saturn's rings are much younger than Saturn.

Thinking Rings around the Universe



Adolf Schaller

The idea of a ring-shaped celestial object was not an accepted notion when Galileo first looked at Saturn in 1610. But once it was established that a ring did exist around Saturn, astronomers began to think about other celestial phenomena in terms of rings. Our current understanding of the Milky Way, other galaxies, and the asteroid belt have developed from ideas spawned by the ring model.

Planetary rings are still used today to

Astronomers can determine the ring's maximum age by studying the waves in Saturn's rings. Careful measurements of the motions of individual waves allow astronomers to determine both the collision velocity and frequency. These measurements lead directly to a maximum age of the rings. For the A ring this maximum age is 10 million years — much less than 1 percent of the age of the solar system.

Another method of determining the age of rings is

NGC-2336, United States Naval Observatory photo

advance our understanding in other astronomical areas. Rings provide a local laboratory for studying the solar system, accretion disks around stars, and galactic structure.

New findings about the dynamics of rings are advancing studies of similar phenomena. The density wave theories developed for Saturn's rings have major implications for the early stages of planet formation (left), according to research by William Ward of the Jet Propulsion Laboratory. The momentum transferred by density waves can move planetary material substantial distances. Waves may also create gaps in the early stellar nebula where planets cannot form and over which material cannot pass.

The similarities between planetary rings and the physics of accretion disks and galaxies have been studied by Frank Shu of Berkeley. Density waves may contribute to the transfer of material in the accretion disk around a black hole. The waves in Saturn's rings have also led to detailed models for generating and maintaining the spiral structure in galaxies (right).

estimating the transfer of momentum between the ring and the moons at resonances. According to Newton's famous law, if the moons act on the rings, the rings must act equally on the moons. This reaction causes an increase in momentum for the satellite and the satellite slowly evolves outward, away from the rings. The time for some of the moons to evolve to their present distance establishes an upper limit to their age at 1 million to 100 million years.

Based on these facts, I proposed that Saturn's rings (or at least the A ring) are young, perhaps 10 million to 100 million years old. This implies that we live in a special time — "the springtime bloom of planetary rings" — in which Saturn's A ring was created. Although evoking a unique time period for planetary rings may be philosophically unappealing — why should man's existence on Earth parallel the existence of rings around planets? — information from the *Voyager* Uranus flyby and the discovery of partial rings surrounding Neptune make youthful rings, if not more appealing, at least harder to avoid.

The primary objective of the *Voyager* observations of the Uranian rings was to find the ringmoons that constrained the rings to be narrow. This search was partly successful. For the epsilon ring, which contains almost all the mass of the Uranian ring system, two shepherding moons were discovered, one inside and one outside the ring. These moons were at exactly the right locations to hold the ring in place and maintain its sharp edges.

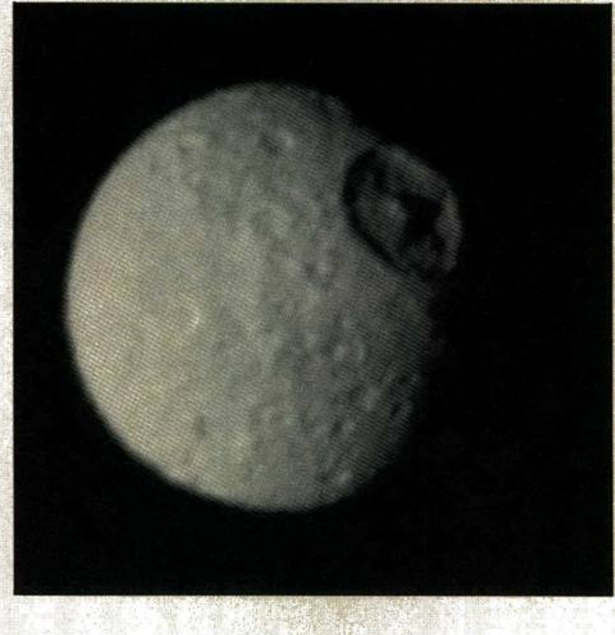
Unfortunately no other shepherds were found to maintain the other nine narrow rings. In addition, limits on the momentum transfer to the two newly discovered moons imply that they, like the ringmoons outside Saturn's A ring, are much younger than the solar system. If they weren't, they would now be farther away from the planet.

The *Voyager* flyby also discovered numerous new dust rings in the Uranian system. Because of the extended atmosphere of Uranus, the particles in these rings suffer a frictional drag that will eventually draw them into the planet's atmosphere, where each particle will vanish as a meteor. Calculations of the lifetime of these rings yield ages of less than one thousand years.

All indications imply that the rings of Uranus are younger than 100 million years. Shepherds too small to be seen by *Voyager* may constrain the other nine narrow rings, but only for a brief time. The dusty rings must have a continuing source, otherwise they would have disappeared eons ago.

At the same time *Voyager* made its observations, ground-based observers consolidated their findings about Neptune's partial rings. Theorists have proposed models that keep the ring particles in place and prevent them from filling the available regions between the observed ring arcs. These models involve the gravitational influence of several ringmoons to hold the rings in place, but these actions are not eternal. The proposed physical mecha-

Destroy a Moon and You Get a Ring


NASA photo (*Voyager 1*)

If, as the weight of current evidence suggests, planetary rings are relatively young objects — much younger than the planets they revolve around — where did they come from? One current theory proposes that the destruction of a moon in a collision with a meteoroid would produce enough material to make a ring.

The heavily cratered surfaces of the moons

nisms do not overcome the natural tendency of the rings to spread; the mechanisms simply slow this tendency by transferring momentum to the ringmoons. As in the other ring systems, the proposed moons of Neptune are probably too small to hold the system in place for the age of the solar system.

All the newly discovered rings and ringmoons seem to be youthful and rapidly evolving. Jupiter's ring must be replenished continually. Saturn's rings transfer too much momentum to their ringmoons. The shepherds are too small (or nonexistent) in the Uranian rings. Neptune's rings are so exotic they almost deny an ancient origin. If planetary rings are much younger than the planets they are associated with, how did they form?

Astronomers know three ways planetary rings may have been created. The first is an exact analogy to the formation of the solar system. The Sun and planets were formed in the collapse of a disk of gas and dust called the solar nebula. Each planet had its own planetary nebula from which the planet and its retinue of moons coalesced. The disk close to the planet cannot contract to form planetary satellites because the tides from the planet are too strong. Only debris remains from the original creation of the planet and its moons. We later see this debris as the planet's rings.

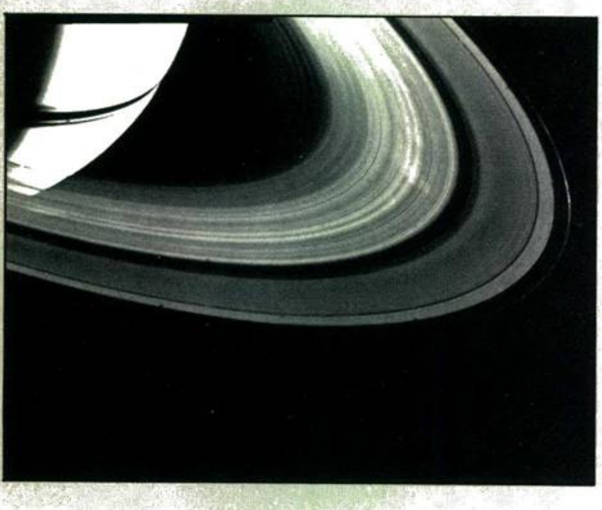
Alan Harris of the Jet Propulsion Laboratory has cataloged some difficulties with this model. A major problem is that small particles forming in the ring region would be dragged quickly into the planet's atmosphere by interactions with other ring particles, the nebula gas from which they are forming, and infalling meteoroids from other parts of the solar system. Although this was the most popular theory before the advent of space exploration of the outer planets, is now seems only marginally acceptable.

A second proposal, first advanced by Edouard Roche in the nineteenth century, is somewhat more exciting. If a moon of the planet were to come too close to the planet, the moon passes a limit (the Roche limit) where the tidal force from the planet exceeds the moon's gravity and can pull the moon apart. The resulting debris quickly collapses to form a flat ring circling the planet. The major portions of the known planetary rings do indeed lie within the Roche limit.

The difficulty with this proposal is moving the satellite from the safe position where it formed to within the Roche limit where the satellite is torn apart. This requires a relatively unusual situation or a large body from elsewhere in the solar system to pass very close to a giant planet. It was easier to consider this possibility when only Saturn was known to have rings: One ring system could have been created by a very rare event, but it is hard to believe this unlikely event occurred around all the ringed planets.

A third possibility was proposed recently by Eugene Shoemaker of the United States Geological Survey, based on studies of the heavily cratered surfaces of the moons of the outer planets. The destruction of a satellite by a giant impact would naturally leave behind a ring. Saturn's moon Mimas displays an impact crater from an object nearly large enough to smash the moon to bits, which suggests that some satellites have already been destroyed.

If a moon small enough to orbit inside the Roche limit was broken apart by an impact, the fragments would collide and gradually grind themselves down to form a ring.



NASA photo (*Voyager 1*)

around the outer planets suggest that such a cataclysmic collision can occur. One of Saturn's moons — Mimas — displays a crater caused by an impact nearly large enough to shatter the moon (left).

It wouldn't take very large moons to create the rings we see today. The total mass of Saturn's ring system (right) is equal to a moon only 200 miles across, which is one-tenth the size of Earth's Moon. The rings of Jupiter, Uranus, and Neptune could be made from moons only 10 miles across.

Rings formed in this way after the creation of the planets would avoid friction from the other components of the early solar system. Rings could have been more common, perhaps existing at one time around each of the planets. The ringmoons we see now in the same region as the rings can be understood as the largest pieces of debris left over from the destruction of an earlier satellite.

These ringmoons are the most likely source of the young rings we see today. As such they indicate that planetary rings are not a phenomenon limited to a special "springtime" era in the history of the solar system but the result of an ongoing process of creation and destruction.

If Shoemaker's theory is right, we know many of these small moons have already been destroyed. The lifetime of existing moons is short, perhaps 1 billion years at most. We know that a single moon 50 miles across has as much material as the A ring; the rings of Jupiter, Uranus, and Neptune could be made from moons only 10 miles across. And such moons are not hard to find: We continue to discover new ringmoons in the *Voyager* data, and many others are probably too small to have been detected. Each is a reservoir of material waiting to be turned into a small ring by a collision with a passing comet.

From these ideas we can describe the life history of a ring. It begins as a small moon near a planet. A collision with a passing meteoroid destroys the moon. The fragments spread. First they form a small ring arc, later a narrow ring, then a broader ring. As the fragments spread, the ring visibility declines as fewer particles occupy any area and the particles are ground down by further micrometeorite impacts. Eventually a transparent, ethereal ring like those of Jupiter is all that remains. At some later time the ring material is gone, swept up by other ringmoons, dragged into the planet's atmosphere, or ground to dust.

The rings formed from massive moons may outlast the solar system. This is probably true for Saturn's broad rings. However, these rings are now seen as the exceptions. The rings of the other planets arise as old comets and other space debris shatter ringmoons. The rings of Jupiter, Uranus, and Neptune are a passing stage, to be replaced later by newer rings. Such a process has continued since the early days of the solar system. In this case there must have been many more planetary rings at an earlier time. Perhaps even Earth had its own ring system that has since disappeared.

The study of planetary rings has now returned to a stage reminiscent of Galileo's first discoveries. In just the last few years numerous new types of rings have been discovered. The phenomenon of planetary rings, once thought unique to Saturn, is now common to all the giant planets and, perhaps, originally to all the planets.

The challenges we face now, as in Galileo's time, are not just to understand our new findings but to overcome our preconceptions and arrive at a new understanding of planetary rings.

Larry W. Esposito, chairman of the Voyager Rings Science Working Group, has been an investigator on several planetary space missions, including Pioneer Venus, Voyager, *and the upcoming* Galileo *and* Mars Observer *missions. He is associate professor at the University of Colorado (Boulder) Laboratory for Atmospheric and Space Physics and the Department of Astrophysical, Planetary, and Atmospheric Sciences.*

Possible Planetary Systems Discovered

by Richard Talcott

A "planetlike" companion only 1.7 times more massive than Jupiter orbits Gamma Cephei. Epsilon Eridani has a companion less than ten times Jupiter's mass. Strong evidence supporting these claims was presented by a group of Canadian astronomers at the joint meeting of the American Astronomical Society and the Canadian Astronomical Society, held June 14-18 in Vancouver, British Columbia.

Bruce Campbell of the Dominion Astrophysical Observatory in Victoria, British Columbia, and Gordon Walker and Stephenson Yang of the University of British Columbia in Vancouver announced preliminary results from their ongoing, six-year survey of sixteen nearby stars. The researchers offered somewhat weaker evidence for the existence of low-mass companions around five other nearby solar-type stars. The team credits its discovery to a much more accurate method of measuring the small changes in stellar motion caused by the presence of an orbiting companion.

The motion of any star accompanied by a companion object is perturbed by the gravitational pull of that object, and the size of the perturbation is proportional to the mass of the companion. This deviation can manifest itself as a cyclic change in the star's radial velocity —the star's motion along our line of sight — as the two objects revolve around their common center of mass. These radial velocity variations show up in the star's spectra as Doppler shifts in the wavelengths of light coming from the star. Because the star is so much more massive than the companion, these variations and thus the Doppler shifts are very small — only a few meters per second.

To achieve the sensitivity required to detect this tiny wavelength change, the researchers employed a new technique to measure relative radial velocities accurate to within 13 meters per second. This represents an improvement in sensitivity of roughly fifty times over previous measurements.

The key to this technique is having light from the star pass through a tube containing hydrogen fluoride gas before the light enters the spectrograph. The gas absorbs light, adding a set of narrow absorption lines to the spectrum. These lines provide a constant "reference frame" for measuring the positions of spectral lines in the Doppler-shifted spectrum of the star. The team made the observations in near-infrared light with the 3.6-meter Canada-France-Hawaii telescope on Mauna Kea.

Gamma Cephei is the only one of the seven stars for which a full period — 2.7 years — has been observed and for which a tentative mass for the companion can be assigned. The amplitude of the velocity change was 25 meters per second, so the mass of the companion is 1.7 times that of Jupiter. (In comparison, Jupiter causes a 12-meter-per-second velocity variation in the Sun's motion.)

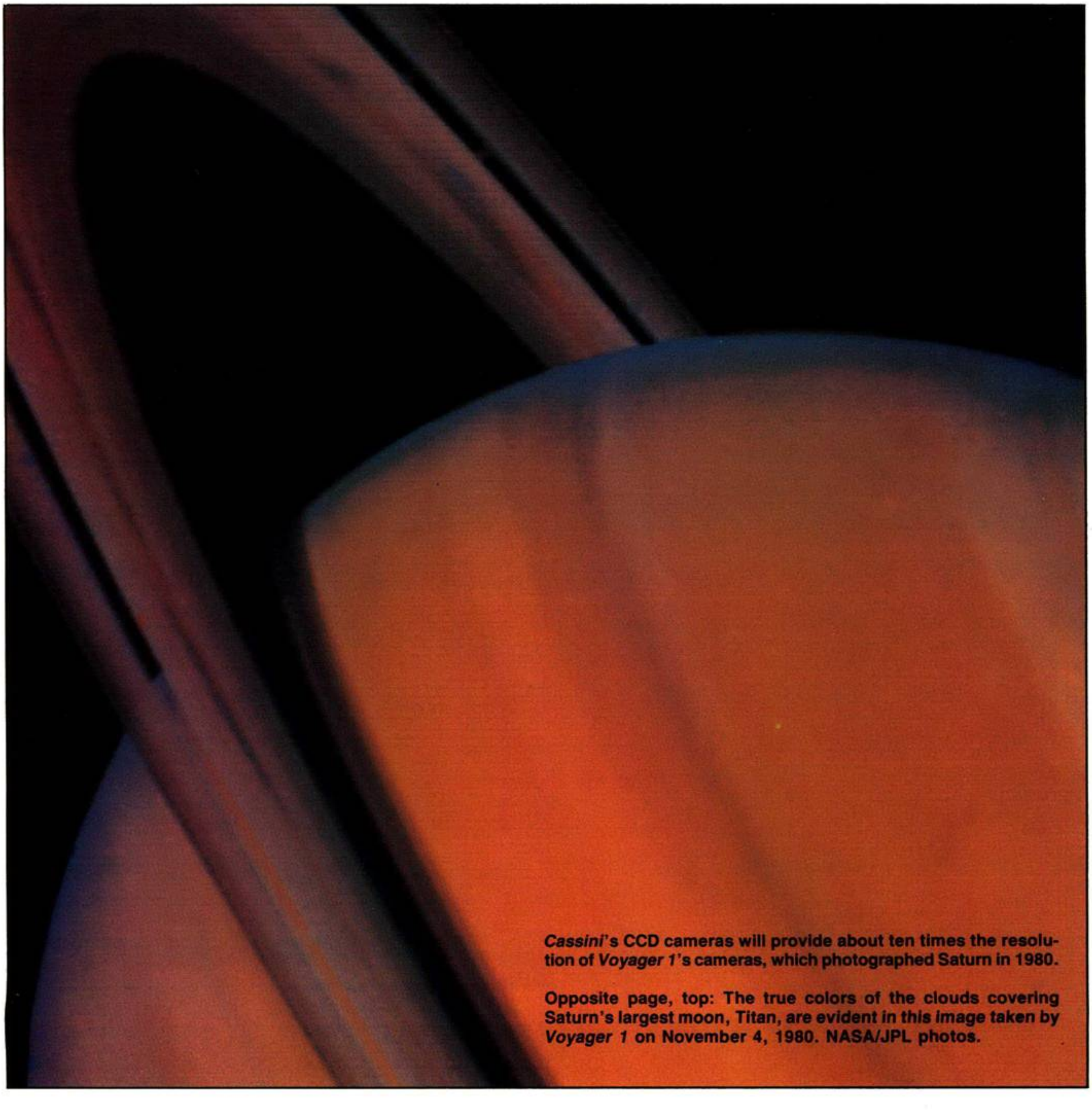
The other possible companions have masses between one and ten Jupiter masses. The upper limit is derived from the inability of prior astrometric surveys to detect any companions. If companions more massive than about ten Jupiters were orbiting these stars, astronomers could measure the small wobble in the stars' positions. The lower limit is set by the sensitivity of the observing technique.

Campbell, Walker, and Yang plan to continue monitoring the stars in their survey and hope other astronomers will now seek to confirm their observations. Although they hesitate to call these newly found objects "planets," the team members are quite sure that the velocity variations they have measured are evidence for companion objects a few times the mass of Jupiter. As Campbell said when summarizing the group's findings, this is "the best evidence yet for planetary systems."

Opposite page: What kind of worlds orbit other stars? What similarities and differences might there be to planets in our own solar system? Artist Michael Carroll portrays a three-Jupiter-mass companion, a world he shows as both familiar and exotic, with its retinue of moons as it orbits Epsilon Eridani.

CASSI

Sending an exploratory craft to Saturn and a probe to Titan is a worthwhile venture. The



Cassini's CCD cameras will provide about ten times the resolution of *Voyager 1*'s cameras, which photographed Saturn in 1980.

Opposite page, top: The true colors of the clouds covering Saturn's largest moon, Titan, are evident in this image taken by *Voyager 1* on November 4, 1980. NASA/JPL photos.

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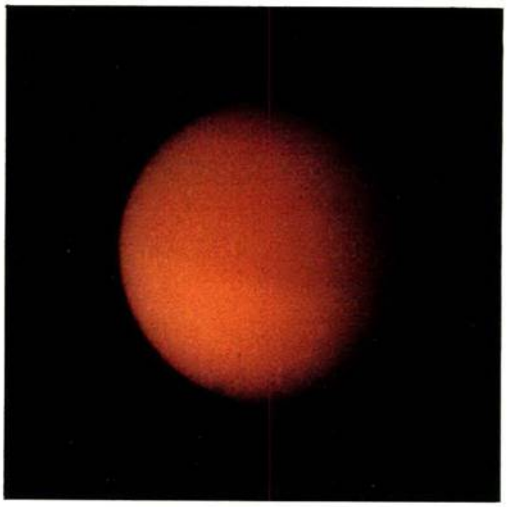


big question is: Will it happen?

by Donald Frederick Robertson

The spacecraft approaches from "below" Saturn at an angle steeply inclined to the planet's orbital plane. The first flyby will sweep between the tenuous G ring — the outermost ring — and the satellite Janus. Once "above" the ring plane, the spacecraft's thrusters will fire for two hours to place the spacecraft in orbit.

About fifty days later the spacecraft reaches the high point of its orbit. A rocket fires to raise the orbit's low point to 390,000 kilometers, away from the danger of the rings. This maneuver also directs the spacecraft toward its first flyby of Titan, where it will release a probe that will photograph Titan's clouds and, perhaps, its surface.

Depending on the outcome of the United States' current crisis in space and on whether or not scientists can overcome some rather formidable engineering obstacles, this Saturnian scenario could become a reality around the turn of the century. Already well into the planning stage, the *Cassini* Saturn orbiter and Titan probe mission, named after the seventeenth-century Italian astronomer Giovanni Cassini, could be NASA's next major exploration of a giant planet after the *Galileo* Jupiter orbiter mission.

Involved is a Saturn orbiter for studying the composition of Saturn's atmosphere and investigating the dynamics and composition of its ring system and a probe — designed by the European Space Agency — to plumb cloud-covered Titan, the only moon in the solar system with a dense atmosphere.

Such an ambitious project seems especially quixotic in this day of budget cuts and the ongoing, paralytic self-examination of U.S. goals in space. Moreover, engineers acknowledge that even without these problems the *Cassini* mission is a difficult undertaking.

According to John Beckman, head of mission design at the Jet Propulsion Laboratory, one of the biggest obstacles is finding a balance between launch energy and travel time. Sending a massive spacecraft as far as Saturn in a reasonable amount of time nearly reaches the upper transport limits of the space shuttle, even if a high-energy Centaur upper stage could be used to send *Cassini* out of Earth orbit. Since the Centaur program was canceled in the wake of the *Challenger* accident, the weight of the *Cassini* spacecraft has become an even bigger problem.

Beckman estimates that the shuttle/Centaur's launch performance must be improved by a factor of four if *Cassini* is to reach Saturn efficiently. The current plan calls for launch in 1995 aboard a Titan IV Centaur.

Because a direct flight to Saturn is impractical with shuttle-class technology, *Cassini* will use a "delta-Vega" (delta-V) trajectory, a technique for changing spacecraft velocity. The delta-V maneuver was developed for *Galileo* when that mission was designed to use a shuttle/Inertial Upper Stage combination in the early 1980s.

A delta-V trajectory will place *Cassini* in a two-year cometlike orbit around the Sun. *Cassini*'s low point initially will be the same distance as Earth is from the Sun, according to Stuart Kerridge, *Cassini* mission design engineer; Kerridge's predecessor Kerry Nock, supervisor of JPL's Advanced Projects Group; and Dave Bender, a member of that group's technical staff. *Cassini* will then coast into the inner asteroid belt, 330 million kilometers from the Sun, where thrusters will fire, slowing the spacecraft by 500 meters per second in order to decrease the spacecraft's low point to 0.9 astronomical unit.

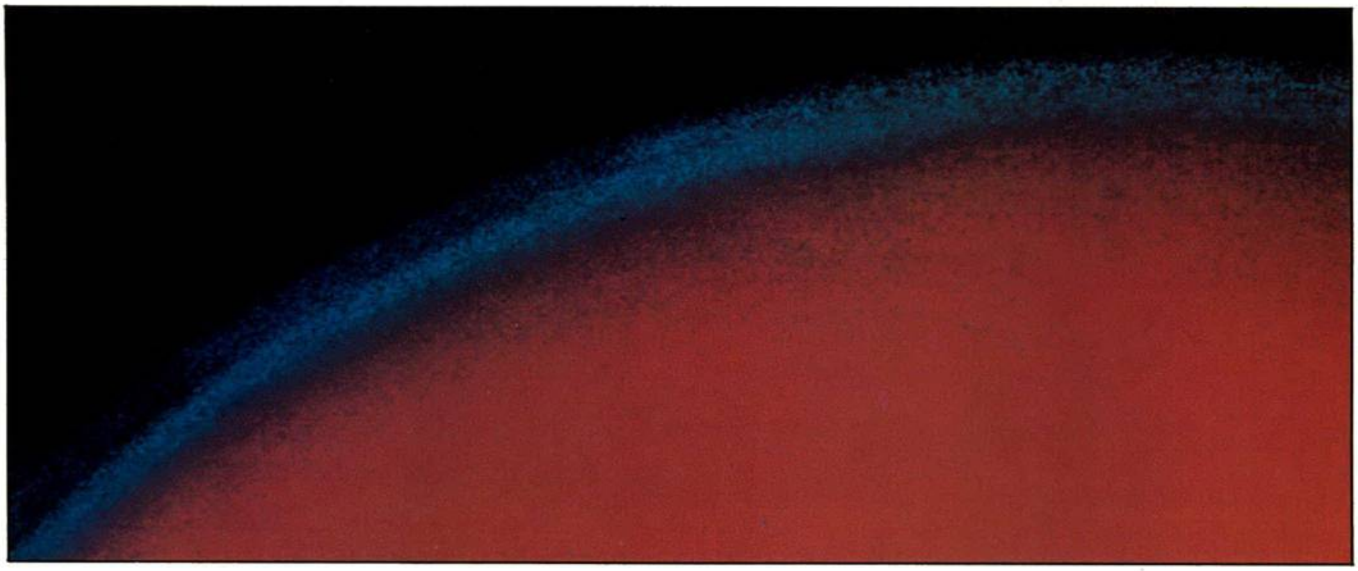
Two months after reaching this low point, as *Cassini* again climbs the outward leg of its orbit, it will fly past Earth. The gravitational energy derived from that flyby will sling the spacecraft first toward Jupiter and then to Saturn.

Resigned to taking the long way to Saturn, mission planners are determined to conduct as much science as they can along the way. Beckman says the Jupiter encounter is a bonus for the mission and that significant science will be achieved even though the flyby will be brief. Moreover, Beckman says that engineers are considering thirteen potential asteroid flybys during *Cassini*'s first return trip to the inner solar system (after the delta-V burn) and six more candidate asteroid flybys on the way to Jupiter.

The unfortunate aspect of a delta-V trajectory is that although it saves fuel, it results in a longer flight time. *Cassini* will take 6.8 years to reach Saturn (arrival is expected in 2002) and then will study the planet and its satellites for four years.

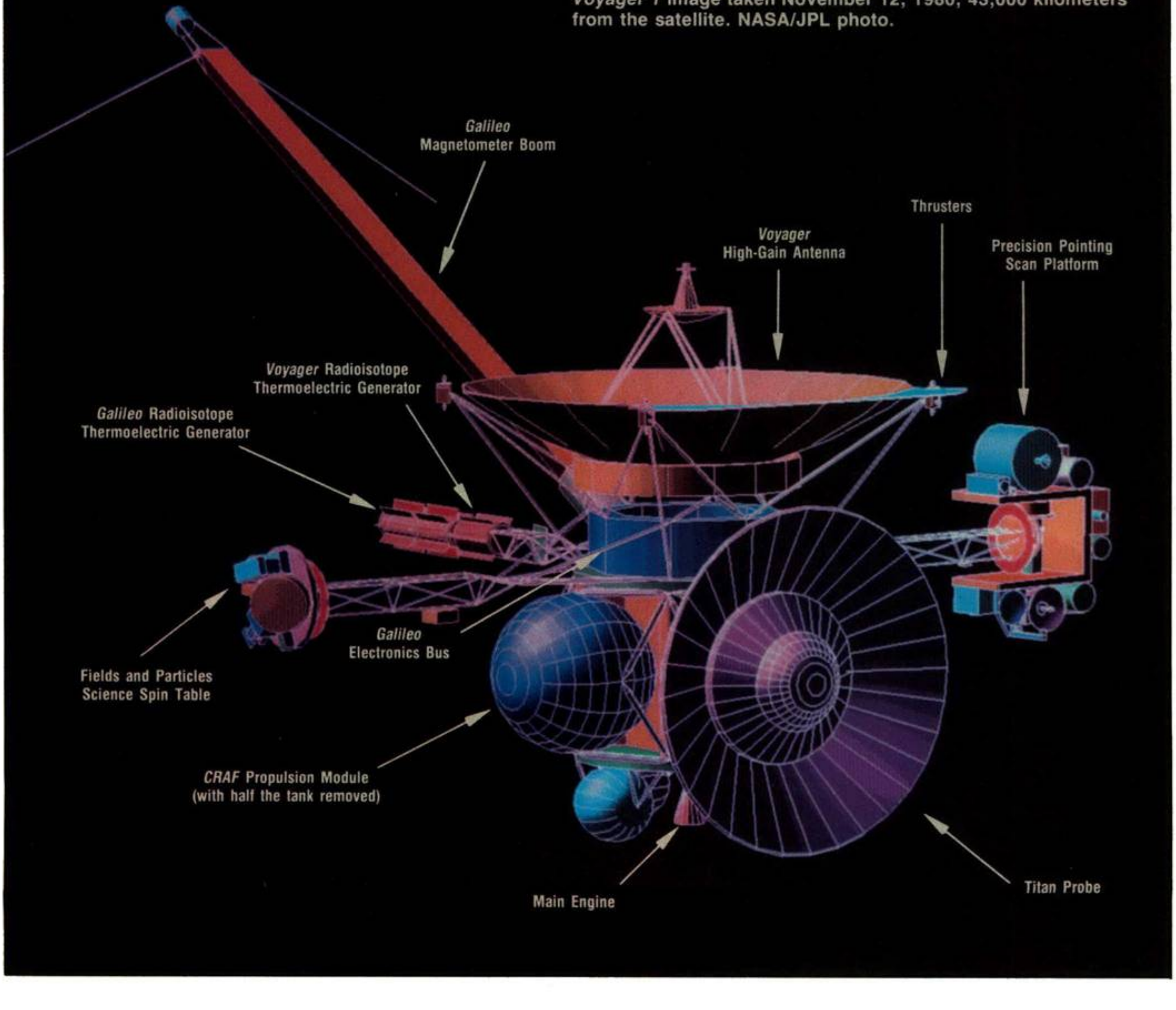
The Titan Probe

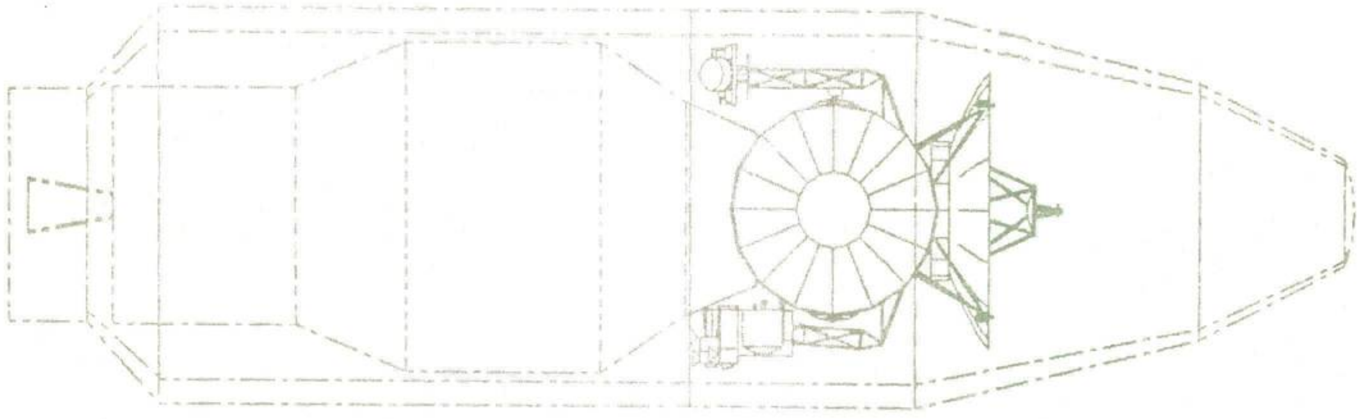
Another important aspect of the *Cassini* mission will be the Titan probe, which will be dispatched from the orbiter after the spacecraft enters the Saturnian system. The probe's first job is to sample Titan's atmosphere. The



Cassini will be the second interplanetary mission to use the Mariner Mark II spacecraft (after *CRAF*). Mark IIs were designed for assembly on a semi-production-line basis from common spacecraft components. NASA/JPL illustration.

Above: Titan's thick haze layer can be seen in this enhanced *Voyager 1* image taken November 12, 1980, 43,000 kilometers from the satellite. NASA/JPL photo.


Galileo Magnetometer Boom
Thrusters
Voyager High-Gain Antenna
Precision Pointing Scan Platform
Voyager Radioisotope Thermoelectric Generator
Galileo Radioisotope Thermoelectric Generator
Galileo Electronics Bus
Fields and Particles Science Spin Table
CRAF Propulsion Module (with half the tank removed)
Main Engine
Titan Probe



probe's other task will be to report on the nature of the satellite's surface, which lies hidden below a global deck of aerosol haze. However, because the type of surface is unknown (is it rock, ice, water, or a combination of these?), imposing questions remain about what kind of landing device to use.

Fortunately, however, the Titan probe will not have to be as sophisticated as its predecessor, the *Galileo* Jupiter probe. Unlike that probe — which will be released 150 days before *Galileo* encounters Jupiter and will thus be moving at a velocity of some 48 kilometers per second — the Titan probe remains attached to *Cassini* after the spacecraft slows down to enter the Saturnian system. This greatly simplifies the probe's entry system because *Cassini*'s orbital velocity at Saturn will be much slower than the velocity required to reach the planet. Hence the probe's entry velocity into Titan's atmosphere will also be less, making an expensive heat shield — like that of the *Galileo* probe — unnecessary.

However, this saving in velocity will be made at the price of substantially greater fuel consumption, which is necessary to slow down the spacecraft when it enters into orbit around Saturn. Because the probe is essentially dead weight, it must be released from the orbiter as soon as possible. This is planned to occur before the first Titan flyby.

After the probe is released, it coasts for several days toward cloud-covered Titan. Then, shortly before the probe strikes Titan's atmosphere at 7.1 kilometers per second, a 2.8-meter cone-shaped aerodynamic brake interacts with Titan's atmosphere like a parachute to slow the probe to subsonic speed some 200 kilometers above Titan's surface. This slowing allows instruments to start working near the top of the moon's permanent fog. After the aerodynamic brake is released, a small explosive causes a drogue parachute to be deployed through a hole near the center of the probe's aft cover, which in turn pulls the cover away and allows the main parachute to open. Vanes mounted on the housing should stabilize the spinning spherical probe. More pyrotechnic devices blow off covers to open inlets and viewing ports.

After one hour of observations in Titan's upper atmosphere, the large parachute is detached to speed the probe's descent, and then a much smaller parachute controls the probe's fall to the surface.

No soft landing of the probe is currently being considered. Nevertheless, the probe may survive impact with Titan's surface, according to Charles Elachi, division manager of JPL's Earth and Space Sciences Division. If the probe survives, measurements of Titan's surface would be made both before and after impact. The main problem with considering post-impact survival options, says Elachi, is that scientists "have absolutely no idea what Titan is like under the clouds."

What will the probe land on? Among current theories is that Titan's surface is entirely covered by liquid nitrogen or methane oceans. Continents (or the low rims of impact craters) made of water-ice frozen nearly as hard as rock, may rise above this sea. Some planetary scientists even speculate that the whole surface is covered with hydrocarbons that fall like snow from the orange "smog" obscuring Titan's surface.

Orbiter Radar to Scrutinize Titan

One of the most exciting aspects of *Cassini*'s instrument package is the orbiter's proposed radar. Each time the orbiting mother craft nears Titan, it will direct a powerful radar beam at the surface capable of resolving between five and ten kilometers of surface detail and of measuring surface altitudes up to three kilometers. The orbiter will fly as close as 1,000 kilometers above Titan's surface, which is within the satellite's upper atmosphere, and should pass over a slightly different part of the moon's surface each time, depending on how Titan rotates with respect to Saturn. (Titan, like the Moon, always keeps one hemisphere toward the planet, scientists believe.)

Alternatively, the radar may use *Cassini*'s 3-meter high-gain antenna, normally used to communicate with Earth, for very limited application of Synthetic Aperture Radar (SAR) techniques. SAR uses a spacecraft's orbital motion to "synthesize" a giant radar antenna. This provides high resolution over a very small area, less than 1 percent of Titan's surface. This is because SAR techniques produce so much data that the spacecraft could not broadcast it all back to Earth.

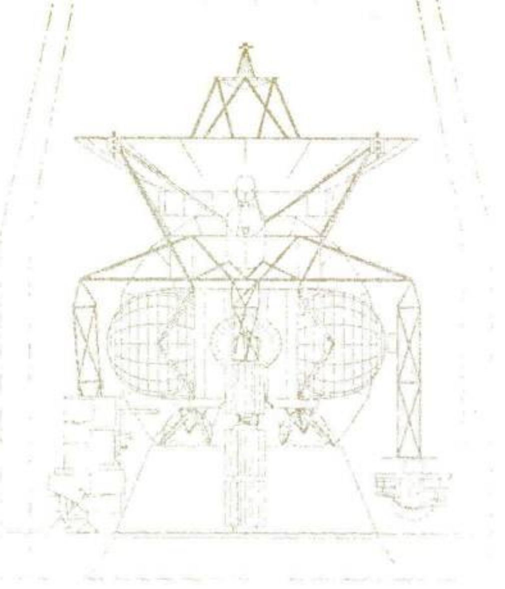
But even with low-resolution radar, scientists will sound the depths of Titan's ice or oceans, observing layering and the interfaces between geological formations. The radar may even see precipitation in methane clouds.

Cassini's Complement of Instruments

The orbiter will also carry charge-coupled device (CCD) cameras, similar to those on *Galileo*. Elachi expects them to provide around ten times better resolution than

Titan Data

Diameter	5,150 kilometers (solid body diameter)
Orbital Radius	1,221,000 kilometers
Orbital Period	15.95 days
Visual Magnitude	8.4
Mass	1.36×10^{23} kilograms
Density	1.88 g cm^{-3} (almost twice that of water)
Surface Pressure	1.6 times that of Earth
Surface Temperature	−168° C



that of *Voyager*'s best Saturn images. Despite this increase in resolution, individual particles in Saturn's rings cannot be discerned. However, Elachi says that observations of starlight filtering through the rings may provide important information on the distribution of different kinds and sizes of ring particles.

Ultraviolet and infrared spectrometers will measure the composition and structure of Saturn's upper atmosphere and will also look for evidence of electrical storms. Other orbiter instruments may include equipment for plasma and dust analysis, ion mass spectrometers, magnetometers, and low-energy plasma instruments.

Some of the candidate payloads for the Titan probe are:

- Atmospheric structure instrumentation with accelerometers and temperature and pressure sensors.
- A neutral mass-spectrometer and gas chromatograph to determine the composition of the atmosphere.
- A nephelometer to measure cloud-particle sizes and distributions.
- A descent imager and near-infrared spectrometer to measure the spectrum of Titan's atmosphere in the visible and near-infrared and, possibly, image the surface during the last phase of the descent.
- An aerosol collector and pyrolizer to analyze the chemical makeup of gas and dust particles in Titan's atmosphere.
- A lightning and radio emission detector to detect the presence of lightning and to measure cloud turbulence. By observing lightning-generated radio waves, this instrument should yield information on atmospheric composition, structure, dynamics, and other properties.

But Will *Cassini* Happen?

The *Cassini* mission would be the second mission to use NASA's new Mariner Mark-II spacecraft (the first is the *Comet Rendezvous and Asteroid Flyby* mission [*CRAF*]), which was advocated by the Solar System Exploration Committee of the NASA Advisory Council for a series of deep-space missions. In order to cut overall costs, the Mark-IIs are designed to be assembled on a semi-production-line basis with common components and support facilities. But if the savings are to be realized, Mariner Mark-II spacecraft must be built and flown on a regular basis.

And here is where the problems begin to creep in. Beckman says that the delay in starting the *CRAF* mission, which was scheduled for a 1988 new start, will in turn delay *Cassini* a year. Such a delay may also gum up the European Space Agency's progress in constructing the probe. The European space science budget is extremely limited, so absorbing delays is difficult for ESA. As U.S. scientists know all too well, delays in large-scale technological projects cost money, and European scientists don't have any money to waste. On the positive side, European space scientists have more say than their American counterparts about how their budget is spent.

Beckman suggests the momentum of ESA's space research programs may encourage the United States to conduct its own long-term planning. Nevertheless, careful planning can be effectively undone by governmental budget cuts. Even if the administration grants a 1991 *Cassini* new start, and if the Office of Management and Budget okays it, the project is likely to face Congress in an environment of multibillion-dollar-per-year Federal budget deficits in tandem with major space shuttle and space station expenditures. None of these factors will likely improve *Cassini*'s chances for approval.

In its favor, should the United States approve any new planetary missions, *Cassini* has a good chance of being chosen because, despite the obstacles mentioned earlier, it is a relatively inexpensive outer solar system mission. *Cassini* does not attempt to answer expensive scientific questions, such as: "Is there life on Titan?" Nor does it use a custom-designed spacecraft on which to carry the instruments but a vehicle equipped with standard parts that can be easily produced.

Still, it is disturbing that the attitude toward space research these days is based not on vision and pioneering spirit but on what will fit within funding constraints. The emphasis is on looking for reasons to *abandon* programs rather than pursue them. Might *Cassini* fall under such austere consideration? Whatever the outcome — the exciting exploration of a planet or the cancellation of a promising program — the *Cassini* mission will certainly be a prominent indicator of what the priorities are in the U.S. space program and where space research is going . . . or not going.

Donald Frederick Robertson is a freelance science writer living in San Francisco. His article "Why Can't We Explore a Comet?" appeared in the November 1986 issue.

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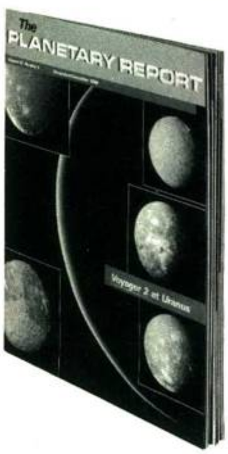

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Co-founders of The Planetary Society: Bruce Murray, Professor of Planetary Sciences, California Institute of Technology (seated left); Carl Sagan, Director, Laboratory for Planetary Studies, Cornell University (seated right); Louis Friedman, Executive Director (standing).

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Thunderbolts Can't Short-Circuit Texas Star Party

The evening looks promising. The Sun is setting behind the craggy hills and the west Texas sky is still clear. There is only a slight breeze, quite different from this afternoon when dust devils randomly crisscrossed the telescope fields, carrying off eyepiece caps, scraps of paper, and trash bags used to cover telescopes. But it's quiet now, the air feels fine and dry, and no clouds are in sight. It looks like a beautiful night for the Texas Star Party.

In a little while it will be fully dark, and except for the innocuous red lights bobbing in the dark like will-o'-the-wisps as observers meander about, that darkness will be absolute. At sundown white light and traffic are banned, which makes the TSP sight — located on the 3,500-acre Prude Ranch in the Davis Mountains, a few miles from McDonald Observatory — a veritable dark-sky paradise for deep-sky observers. These lighting restrictions are inviolable. Heaven help you if you unwittingly switch on your car headlights and irradiate someone just wrapping up an hour-long exposure of some obscure nebula. You would fare better if you got caught drinking whiskey on the front porch of a Baptist church in a dry county.

As popular as the Texas Star Party is, many amateur astronomers still don't know what the TSP is all about. The primary objective, of course, is to observe to the point of exhaustion. You have six nights to do this and, if the skies are clear on even half of those nights, you will accomplish your mission.

In addition to quality observing, the TSP also gives you the opportunity to exchange notes with other observers and professional astronomers. You can find out how to build a better telescope shelter or hear what others are saying about the performance of the newest fast film or the progress on the construction of an important research telescope in New Mexico. The TSP is an enriching experience, a time to raise your consciousness about astronomy. It's also a heck of a lot of fun.

Photo by Phillip Scott

On the telescope field you can sense the restrained excitement of the observers as darkness falls. Of course, no one has forgotten that last night also looked promising — until thunderstorms swept out of the southwest! If you could listen to their thoughts as these folks patiently wait out the last vestiges of twilight, imagine the din you would hear rising to the sky like a chant: *Give us just one clear, transparent, cloudless, absolute, all-encompassing, black-to-the-horizon, profoundly dark night. Just one!*

In the twilight I walk down to the front field of the Prude Ranch to see how Jim Link and George Semple are faring. Jim, who is from Hattiesburg, Mississippi, and George, who lives in Chicago, met at the TSP the previous year and decided to pitch camp together for the '87 meet. They offer me hot cups of amoretto coffee as well as leisurely looks through Jim's 12-inch Dobsonian and George's 8-inch SCT. Like a homeless dog I hang around. The talk ranges from CAT scanners, which Jim works on, to astrophotography and telescope accessories. Jim convinces me to buy a Telrad finder at the vendors' hall. I convince him to buy a UHC filter. Granted, the filter costs twice as much as the Telrad, but I can't resist spending other people's money.

It is nearly dark as I make my way to the upper telescope field where Floridians Tom Clark and Vic Menard are fielding questions from observers

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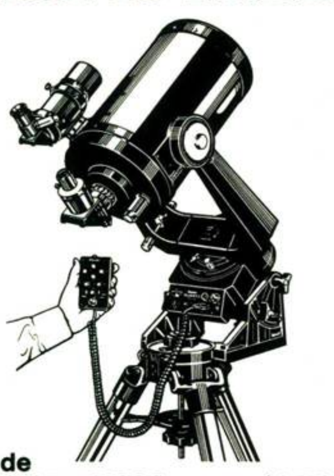

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swarming to look through their homemade 16- and 20-inch fork-mounted Newtonians. The mounts for these telescopes are remarkable. They consist of Styrofoam encapsulated within 1/8-inch plywood and reinforced with 3/4-inch plywood at the stress points; the whole assembly is sealed in fiber glass. Vic shows me how light the mount is by lifting the polar-axis end with one hand.

"Did you look at Omega Centauri?" someone asks.

"I looked at it in the 20-inch," Vic replies. "It's not dark enough yet."

"It's getting there."

"It's getting there?"

"It's got wormholes in it."

"Ooh!"

This is too much for us; we demand to see Omega Centauri. Vic turns the scope on the giant globular and one by one we climb the ladder to take a look. The cluster seems effervescent, as if stars are bubbling forth from the core.

"Fantastic!"

"Geez, that's incredible."

Admittedly these are predictable comments, but if you could see what we see you would be making them too. These observers aren't scientists; they aren't here to take data. They're here to enjoy the unexpected beauty of the night sky. What *can* one say that would adequately express such beauty? ("Pardon me while I have a religious experience"?) I think the statement most often made at the TSP is probably "Oh wow!" And for good reason.

Next we decide to look at M-51, the Whirlpool Galaxy. As Vic locates this face-on spiral, someone remarks that there's "an awful lot of lightning" just over the hill to the southwest.

"Is anybody monitoring the weather here?" someone asks.

"By tomorrow I think we'll be in touch with a weather satellite via a TV hookup at McDonald Observatory," another voice says.

Vic centers M-51 in the field, and we are all treated to a view of this noble spiral and its small companion galaxy. You can trace the arms nearly to their full extent. In the center of the galaxy's gray disk is a bright, pinpoint nucleus. The companion, too, has a compact nucleus, slightly fainter than the M-51 nucleus, and is surrounded by a faint, elongated disk.

"This doesn't look bad tonight," Vic says.

"Well, don't look south," cautions Tom Clark, who is manning the 20-inch nearby.

"I'm not looking south, Tom," Vic replies, his eye to the eyepiece. "Somebody keeps telling me it may rain. I don't want to hear about it."

"There are lightning bolts in those clouds," someone says.

"It kind of smells like rain."

We hear a low, distant rumble.

"I think we should prepare for rain."

Within twenty minutes clouds blot out the stars. Lightning temporarily floods the field with blue light, blinding observers who are scurrying about to cover their instruments. Thunder tolls the end of the evening's observing.

Then it rains. Large drops sound like stones as they strike the blue tarps hastily thrown over the telescopes. In tents, cabins, and trailers all over the ranch you can hear the sound of gnashing teeth.

I am on my way to the bunkhouse when the clouds really let loose. Lightning flashes all around and the irony of being killed by a thunderbolt at a star party does not escape me. Wasn't I just looking at M-51?

Back in the darkened bunkhouse I lie on my bed listening to the rain and the dejected comments of my bunkmates. Many of us have waited all year (in some cases many years) to come to the TSP; we drove hundreds of miles, borrowed time from our wives and families, and spent money we didn't have just to enjoy a few nights of clear, dark skies. So it's natural to be disappointed and a little frustrated when the weather doesn't cooperate. After all, when this week is over, most of us will return to light-polluted skies, chronic cloudiness, or careers that restrict the time we can spend observing.

A peal of thunder rattles the bunkhouse windows.

"There must be an easier way to have fun," someone mutters from a bunk across the room.

I wake to blue skies streaked with only a few thin, high clouds. How long has it been like this? A sinking feeling tells me that perhaps I should have waited out the storm. At breakfast in the high-ceilinged, wood-paneled Prude Ranch dining room I learn the sky cleared at about 4 a.m., but the seeing was not very good. Small consolation! At least I have two more days to go.

Poor seeing conditions are the ongoing topic of discussion for just about everyone. The night sky is not black and clear, as it has been in years past, but burnished with a blue glow almost bright enough to read by. Some say the glow is caused by humidity brought in on the jet stream; others say it is dust sucked into the atmosphere by a tornado that just the week before destroyed Saragosa, a small town thirty-five miles northeast of the Prude Ranch. In any case, the sky hasn't really stayed clear long enough to enjoy the stars even in bad seeing, something most TSP participants would now accept without complaint.

Gary Wray, a Pitney-Bowes customer service representative from Houston whom I met my first day at the TSP, joins me at the table. Gary has a star atlas with him (he seems to be the only guy who consistently carries a star atlas to meals). He reports that he wasn't able to find the Veil Nebula last night before the storm. He wonders if the object can even be seen in his 8-inch SCT. I reply that if we ever get a decent night it should be easily visible in his telescope.

We turn to the Cygnus chart in the atlas. I suggest he begin with Epsilon Cygni and hop over to 52 Cygni, where he should see the western component of the Veil as a winglike haze around the star.

Someone else at the table suggests that Gary also work his way slowly eastward from 52 Cygni and look for a broader band of faint nebulosity.

"It should stretch right out of the field of view," he says, "even with a wide-field eyepiece."

"Well, I'll try again tonight," Gary says. "If it's clear."

I nod, looking out the dining room windows at the sunny morning and the blue sky beyond the oak trees. It's going to be a long day.

So what do we do during the day at the TSP? We wait for night, passing time as best we can. When we should be napping, we swim in the Prude Ranch pool, play tennis, ride horses, climb the hills surrounding the ranch, or visit the vendors' hall and spend money we don't have on filters, books, eyepieces, electric focusers, finder scopes, binoculars, and other goodies. There are opportunities to have long conversations, read, plan the night's observing activities, visit McDonald Observatory, tour the frontier army fort at Fort Davis, and drink malts at the cafe in town.

After lunch the seminars begin in the gym, and these are usually worth attending. Today I listen to a benign discussion of the mysterious optical flashes seen in Perseus and other sky locations. The participants are split about what causes these flashes — tumbling satellites, space debris, or perhaps some form of energetic star.

At 4 p.m. Lynwood Schlabach tells us about how he built a home observatory in Refugio (pronounced Re-FYUR-ee-oh) Texas. It looks like a first-rate job from his slides. The dome, which was professionally manufactured, is mounted atop his garage, and the garage itself has been turned into a work area and study.

After Schlabach's talk Klaus Brasch gives us some tips on taking astrophotos from the city. Not all of us live in the desert or have backyards in rural

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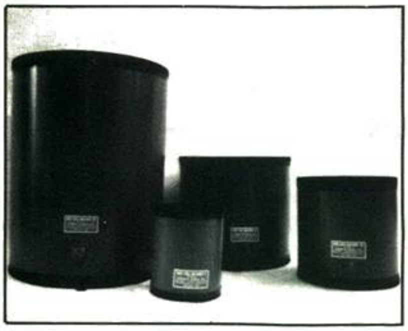

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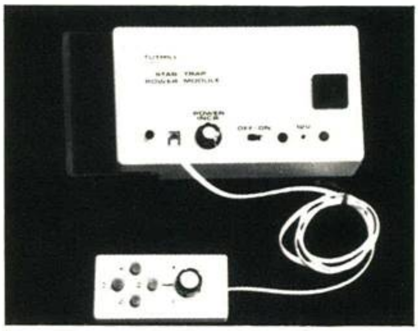

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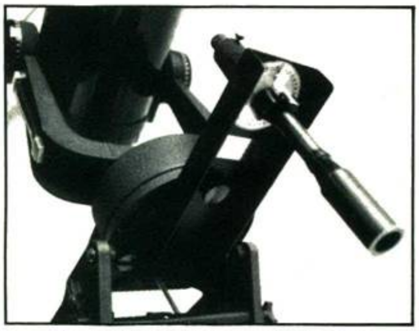

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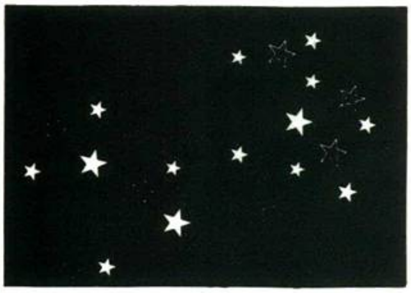

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America. Most of us are tied to the cities and dark skies are a good hour's drive away. Brasch suggests that with filters and some common sense we can take pretty good astrophotos, even though we don't have all the advantages the country astronomer has.

Before you know it, supper is served and we all assemble outside in the long meal line that stretches around the dining room. The Sun is still pretty high and darkness won't be upon us for another three hours, but everyone is anticipating the night. The waiting is tolerable now. The sky is still clear and the air feels dry. Like reckless dreamers we hope.

Hours later amateur observers are back at their stations performing their respective twilight rituals. They pull the blue tarps from their telescopes and set them aside — but do not put them away. Card tables and lawn chairs are set out, and star charts, sky catalogs, and other reference materials are placed on them. Red-lensed flashlights are checked, last-minute telescope collimation adjustments are made.

Gradually the bright stars emerge from the twilight. Arcturus is a lone, brilliant glow nearly overhead. Leo is visible now, as is the Big Dipper, and Spica is a bright blue point in the south. And rising above the hills, heralding the Milky Way, is Antares, glowing dull orange in the thick atmosphere.

With my red miner's light dangling from my neck, I cross the middle telescope field to where members of the Oklahoma City Astronomy Club — organizers of this year's and last year's TSP — are gathered with their array of Dobsonians that includes a 24-inch f/4 Dobsonian, the largest-aperture telescope at the TSP. This telescope has attracted so many people that the owners, David Higgins, John Elrod, and Phillip Scott, haven't been able to do any serious observing since they arrived at the Prude Ranch. Nevertheless, they are having a great time providing everyone else with stunning views of Omega Centauri, NGC-5128 (Centaurus A), the Hercules Cluster, the Whirlpool Galaxy, and the Ring and Dumbbell nebulae.

As I approach their site, a "discussion" is in progress on the merits of double-star observing.

"I tell you that telescope will break looking at double stars," says Elrod, referring to some observers who have commandeered the 24-inch for a look at Epsilon Bootis. (Using such a large telescope to look at double stars is, by some deep-sky observers' standards, a senseless waste of mirror space, sort of like using a grand piano as a plant stand.) "I'm going to cut off half that mirror just to keep you from looking at those dumb double stars," Elrod threatens, though nobody quite believes him.

A little while later Higgins finds Pluto with the 24-inch. The starlike planet is situated between two galaxies. Higgins tries to explain to an observer where Pluto is in the field.

"Okay, you've got two galaxies: a spiral down in the lower right-hand corner of the field and a smaller galaxy in the other corner, and in the middle you've got a fairly bright star. Pluto should be down to the lower left of that star."

Confused observer: "Will it be on my eyepiece left or my eyepiece right?"

Dead silence.

Someone else interjects: "It's directly between two galaxies, one bright star is to the upper right of the planet."

Higgins: "Didn't I just say that?"

Eventually Higgins takes control and turns the 24-inch toward Corvus.

"What's in Corvus anyway?" someone asks.

"The Ringtail Galaxy," Higgins says. "NGC-4038, I think."

While Higgins is looking for the Ringtail, clouds appear ominously above the hills. Lightning flashes in the distance, invoking a flurry of curses and meteorological maledictions. Some observers leave, already resigning themselves to rain and another lost night.

"Are we going to have a monsoon wipe out the astronomy community, the poorest of the poor astronomers?" asks one exasperated observer.

Like a bad dream the first rumble of thunder reaches us. Without comment everyone pulls out the blue tarps and begins to wrap up his scope.

"I hope we don't have any tornados," someone says with a nervous chuckle.

"This terrain is not conducive to tornados," says the resident weatherman. "Of course, you might get struck by lightning . . ."

Phillip Scott, determined to get something on film, turns his camera on the storm and makes exposures of the lightning. After the scopes are safely covered, everyone settles down to watch the light show, oohing and aahing as the strokes fork wickedly across the sky, turning the clouds a light purple. We notice that the lightning flashes and the thunder are coinciding more and more frequently, yet we sit in lawn chairs and on the back of pickup trucks, mesmerized by the approaching storm. Suddenly the field is lit by an exceptionally bright lightning flash; Scott chuckles to himself, pleased his camera is capturing the event.

"That flash was definitely −21 magnitude," someone estimates in a serious voice. We all laugh.

Higgins and I decide to "amble" up to the snack bar as the storm bears down on us. We challenge the storm to do its worst and, of course, worry that it will. While we are there, the wind picks up and large raindrops begin to smack against the snack bar's tin roof. We wait under the porch for the storm to cut loose, but it never does. Instead, the clouds blow over without any more rain, and large patches of clear sky open up in the southwest. Heartened, we hurry back to the field. Stars can be seen overhead through the cloud breaks and soon everyone is exuberantly pulling the tarps off his telescope.

Exhilarated, I sprint to the bunkhouse and load my camera with Konica SR 1600 film. Then I gather my camera bag, tripod, and drive platform and make my way to a service road on the far side of the middle telescope field. Rising well into the sky now is the Milky Way in Sagittarius and Scorpius, punctuated with knots of star clusters and bright nebulae. As unpredictable as the weather is, I'd be a fool not to go ahead and get a shot of this region.

I quickly align the hinge of the platform to the celestial pole and begin an exposure. I make another and still another. The platform is tracking wonderfully. I attach the telephoto and shoot the Lagoon and Trifid nebulae; I take a wide-angle shot of the Rho Ophiuchi region. I look at my watch. It's nearly 2:30 a.m. Can it already be that late?

I turn the camera on the North America Nebula and start an exposure. This time I resolve to go "deep" — at least 15 minutes. As the drive tracks the stars, I stand back, look up, and really take in the sky.

True, the stars are twinkling madly and there's a bluish luster to the sky — not perfect seeing conditions — but you won't hear me complain. After all, the sky could have stayed cloudy and this could be the last night of the star party. I might have missed seeing Omega Centauri and the Whirlpool in the 16- and 24-inch scopes. Jim Link and George Semple might not have brought amoretto coffee. Sixteen hundred speed film might not have been invented yet. I could have been struck by lightning. Things can always be worse.

Fifteen minutes are finally up and I am ready to end this exposure. Just a few more shots and I will be finished with this roll. After releasing the shutter, I look down at my camera platform and notice the heavy dew running down the tripod legs, accumulating on the camera case — thickly covering the camera lens. I wonder: *Is there an easier way to have fun?*

Jeff Kanipe

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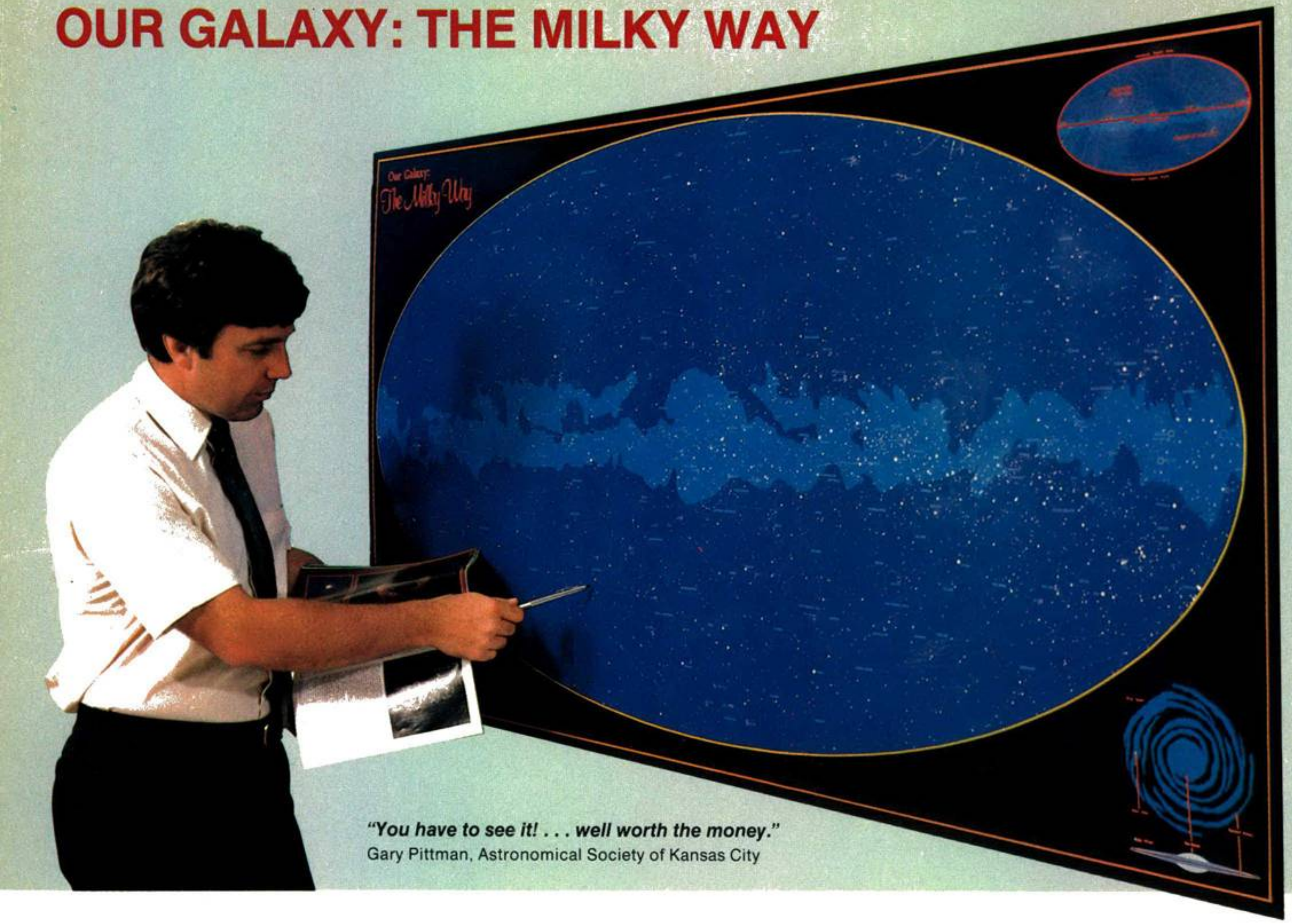

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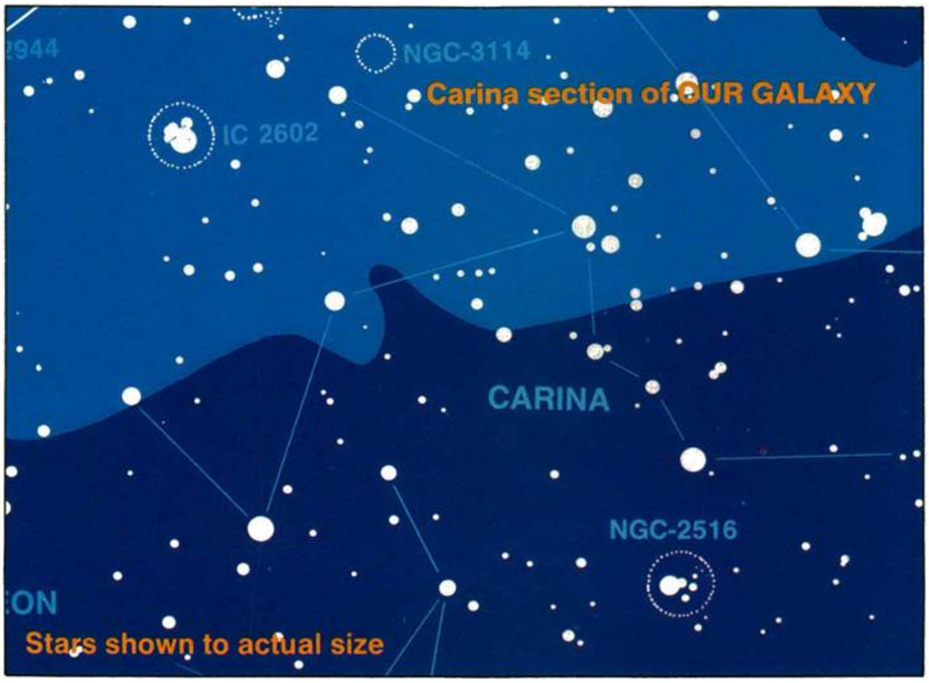

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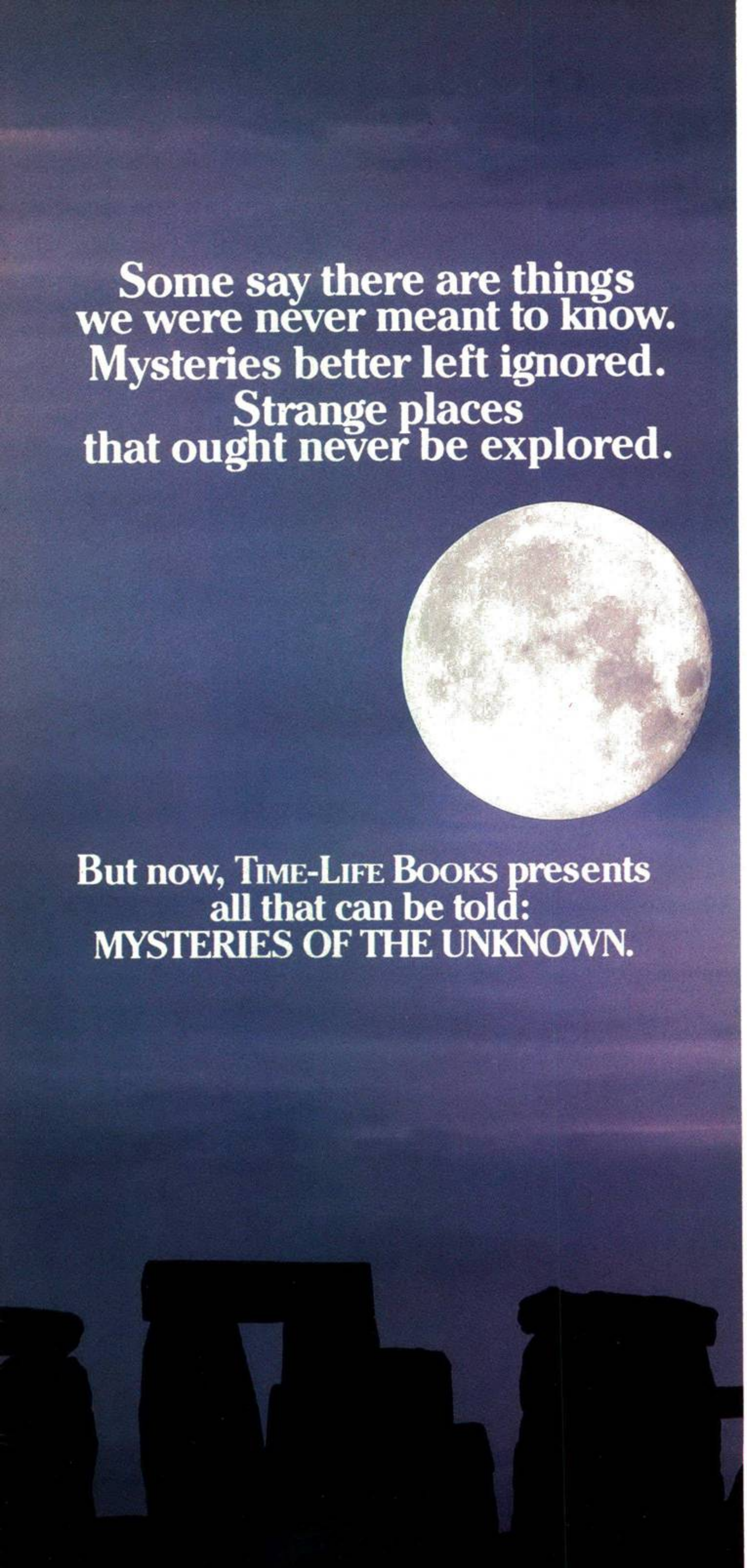
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SPECIAL REPORT

Riverside and the Texas Star Party

Riverside Telescope Maker's Conference

by Richard Berry

Big Bear City, Calif. — It's amazing how rapidly you get used to miracles. Only a few years ago amateur telescopes bigger than 12 inches were rarities, computers needed large air-conditioned buildings, and the only people using image intensifiers did so while flying helicopters over jungle hide-outs.

At the Riverside Telescope Maker's Conference this year I looked through several computer-controlled telescopes, took pictures with an image intensifier mounted on my camera, and saw dozens of 16-inch and larger telescopes around the grounds. The amazing thing was not the gadgets but how rapidly we've grown used to them and how normal and natural using these gadgets feels.

Computer Control for $200

In fact, the most impressive telescope at Riverside this year was a computer-controlled telescope built by David Gedahlia. What made it impressive was the control system he built himself.

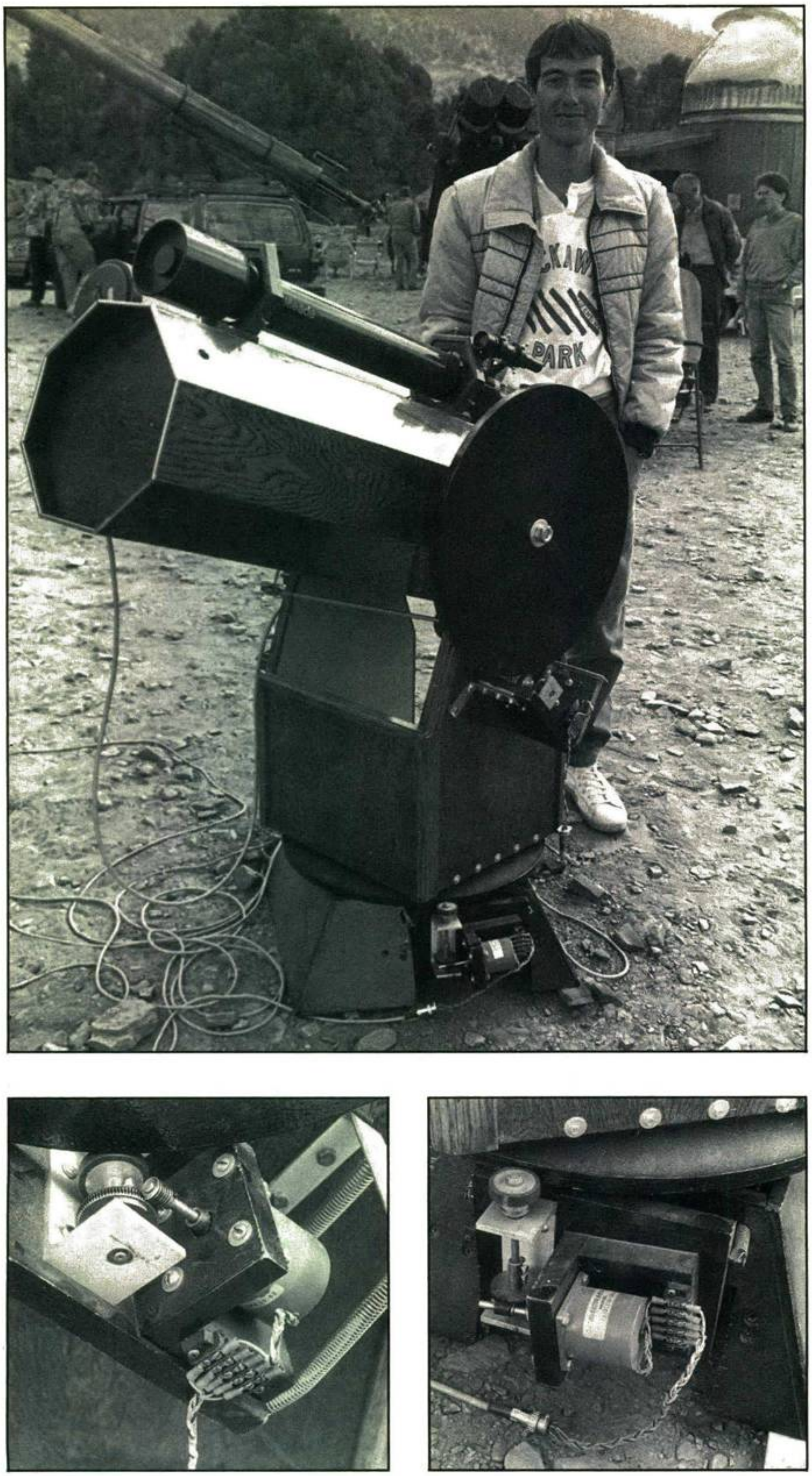
"The total cash outlay was $200, not including the computer, because I had that already," he admits. This telescope began life as a rather ordinary 10-inch f/4.5 Dobsonian; the budding electrical engineer regarded automating it as a challenge. Working with an Atari 800XL computer and some surplus parts, he created a fast, efficient, and remarkably simple system.

The Atari, disk drive, and monitor sat on the tailgate of David's station wagon; cables snaked across the ground to the telescope. Although it looked like an ordinary Dobsonian at first glance, this telescope is distinguished by the unusually large altitude bearing and two small drive motors. A small rubber roller presses against the oversized disk on the altitude axis, and another presses against a large disk on the azimuth axis. Stepper motors drive each rubber roller through a small reduction gear.

Stepper motors are ideal for moving telescopes under computer control. Instead of running at a constant speed in one direction, stepper motors don't turn until their internal windings are energized — and then they take one "step" forward or backward. Each step is a certain fraction of a full turn, depending on the motor, usually 1/8th of a turn. To move the telescope, the computer only has to tell the motor to turn, for example, counterclockwise 352 steps, and the motor will move exactly that far and no farther.

The Atari 800XL can do this easily because it can send bytes directly to the

Below: The main telescope fields at the Texas Star Party.



Above: David Gedahlia stands behind his homemade computer-controlled 10-inch Dobsonian telescope at the Riverside meeting. A program written in BASIC and running on an Atari 800XL drives stepper motors (bottom) on the altitude and azimuth axes. The telescope can locate several hundred objects in a night.

joystick port. To drive his telescope, David simply amplifies these signals so they're strong enough to power the stepper motor and sends them through cables to the motors.

"The software takes care of all the ramping up and down," adds David. That means he has programmed the computer to start the motor slowly, bring it smoothly up to maximum speed, and then slow it down to a joltless stop. "A machine-language subroutine generates the signals that drive the motor," he said, "but everything else is written in BASIC."

From a menu on the monitor the observer selects a constellation and then an object. Working from coordinates stored in the computer's memory or on floppy disk, the control program calculates the object's altitude and azimuth, computes how many steps the object is from the telescope's current position, and then commands the motor subroutines to move the telescope.

Does this $200 system work? "Last night I saw eighty to a hundred objects in Sagittarius, Scorpius, Cygnus, and Lyra," David says with a little grin, but he admits he "wasn't counting."

Tall Telescopes

In the last couple of years refractors have become quite popular with amateur astronomers. Two refractors drew a lot of attention this year: an 11-inch refractor built by Jeff Schroeder and a 4-inch, century-old Alvan Clark refractor restored by Luis Ashelford.

Jeff built his refractor more than a decade ago. He ground, polished, and figured the 11-inch f/16.3 objective lens and constructed a massive mount that towered over him. It was big, beautiful, and backbreaking. When Comet Halley drew near, Jeff decided there had to be a better way. He remounted the huge tube on an altazimuth carriage on top of his station wagon. The result? "I've gotten more use out of this thing in the last two years than I did in the previous ten."

The telescope rests on three Delrin plastic pads that turn on a sheet of Micarta linen-based phenolic-resin plastic and can be raised to a maximum altitude of 63° with a hand-cranked jackscrew. Wooden blocks jammed under the rear bumper help stabilize the car. The eyepiece is low and easy to get to, which was perfect for showing Comet Halley to kids. "I figure seven thousand people saw the comet through this thing," he says, "and it only takes five minutes to set up."

At Riverside, even by starlight, spotting the long tube of Jeff's refractor pointing toward the stars was easy, and there was always a long line stretched out behind his telescope.

The Glow of Old Brass

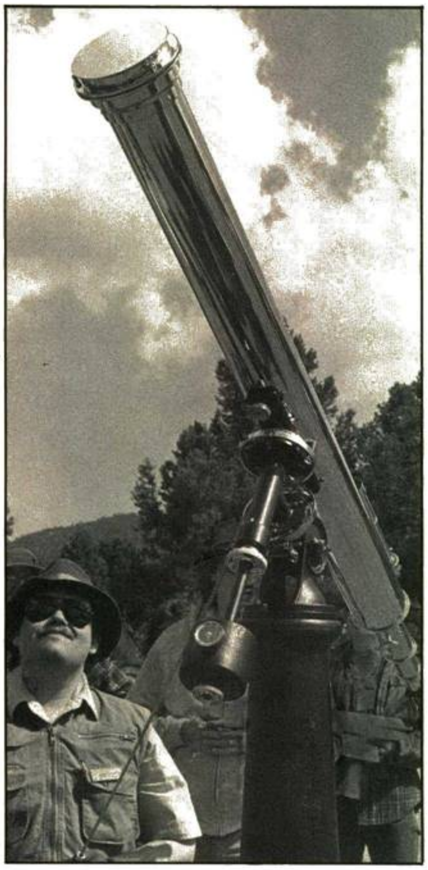
"It took me a year to do it," said Luis Ashelford, as he gazed lovingly at the smooth brass tube of his 4-inch f/15 Alvan Clark refractor. When he got the telescope, its tube was badly dented. "I hand-banged it round again," he said.

Luis did a lot more than bump out the dents. He restored a badly mauled old telescope to tiptop shape. He removed an electric clock drive, tore down the tube and mount, stripped off a century of corrosion, reproduced a dozen missing knobs, replaced missing parts, smoothed and polished rose and yellow brass, and then coated the gleaming parts with polyurethane to keep them shining.

I get a thrill out of observing with an old telescope that's been restored to "like-new" condition. I can imagine seeing things the way they might have appeared a century ago, when we knew so much less about the universe. It was a much smaller universe back then, without quasars, pulsars, or even galaxies other than our own.

A Solid Mounting

One of the most functional modern telescopes at Riverside was a 17-inch telescope built by Robert Pfaff. This fork-mounted Newtonian was as solid as a telescope should be. Although the massive conical polar bearing supporting the welded steel fork testified to many hours of machine-shop work, the result was beautiful and functional.



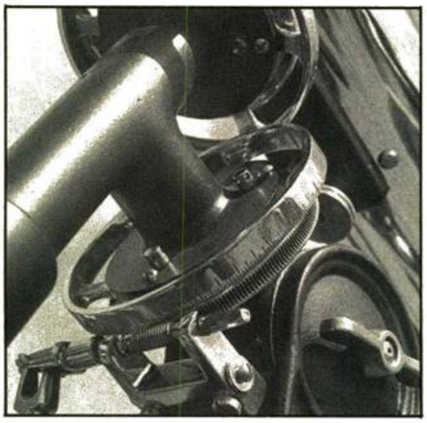
Left: Luis Ashelford beams at his restored 4-inch Clark refractor. Brass setting circles gleam on the black-enameled mounting.

Mounted on a low frame of welded 2-inch by 2-inch steel cross section, the massive conical polar axis was supported by a pillow-block bearing at the south end. The north end rests on two rollers, one driven by a small motor for tracking. Robert constructed the polar cone from a length of 4-inch pipe and a 15-inch disk of aluminum 1 inch thick.

The fork, welded from a 3-inch by 6-inch steel cross section base with 3-inch by 4-inch tines, carried vibrations from the telescope into the cone, which in turn transmitted them to the ground. Robert had done everything right: the telescope didn't shake or wiggle. When I grabbed the eyepiece and gave the telescope a good solid thump, the telescope resisted, and the motion I had started damped out within seconds. This is the way a telescope should behave.

Pictures by Starlight

There are more wonders in astronomy than telescopes, even at a telescope conference. For an hour one night I shot photographs with a Litton M911 image intensifier mounted on my Canon T-70 camera. The circular images sprinkled throughout these pages were taken with this system. In most cases I could not see what I was photographing unless I looked through the camera's view finder.



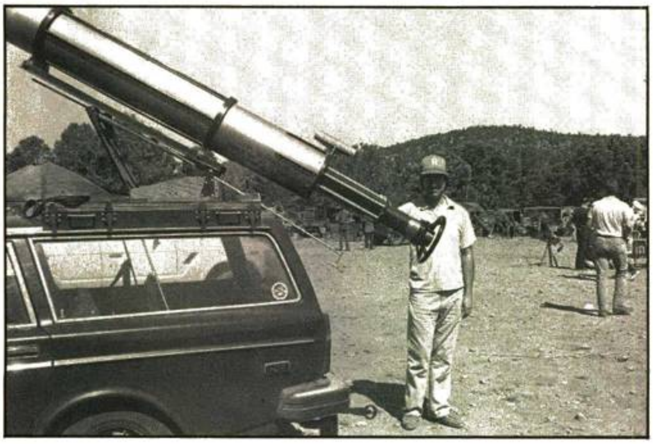
Although these gadgets cost several thousand dollars apiece — not much more than a medium-sized telescope — they boost the effective "film speed" of any camera to 5 million ISO. With an eyepiece they brighten the starlit scene before you several thousand times. I took a hand-held photograph of M-13 through the eyepiece of Robert Pfaff's telescope and got beautiful negatives.

What's even more amazing is how easily you become accustomed to an image intensifier. Five minutes after taking my first picture, I realized I was concentrating on the *composition* of my photographs and had almost forgotten the incredible technology I held in my hands.

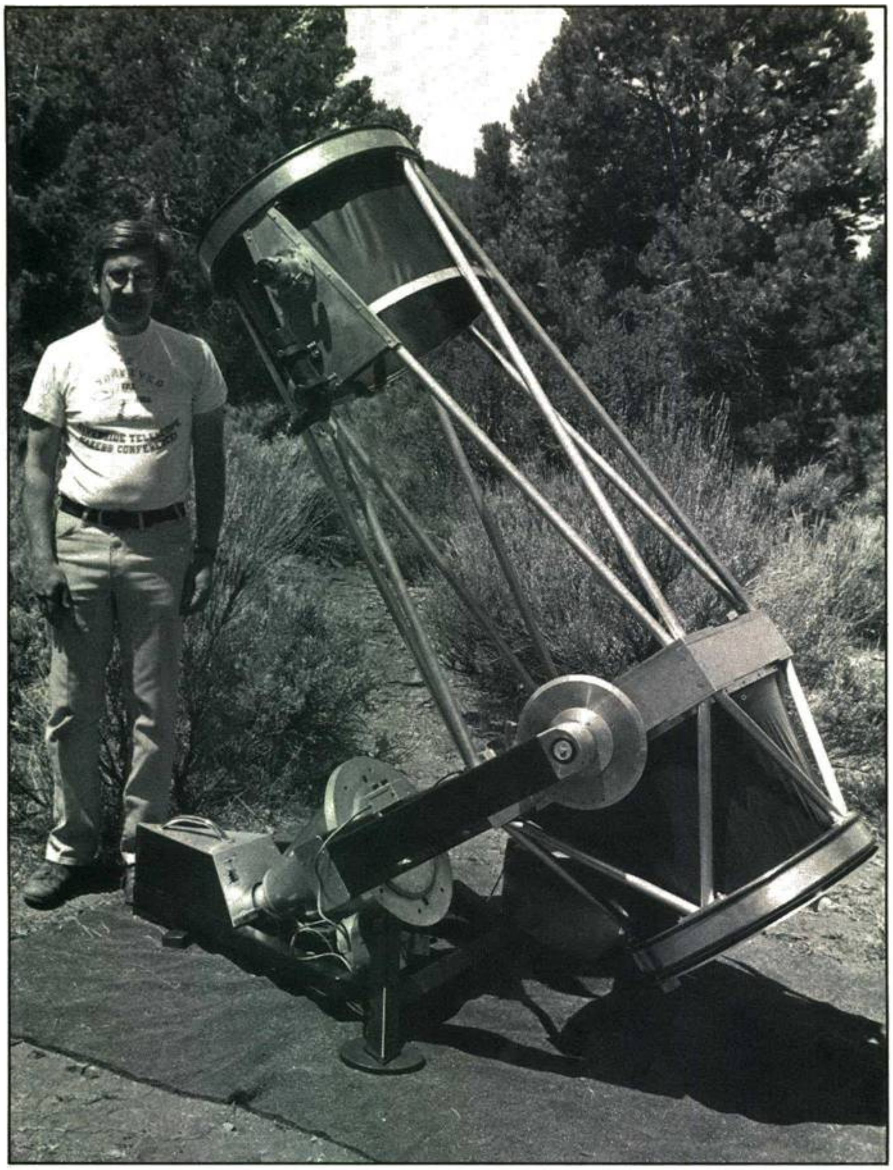
Star Party in the Lone Star State

by David J. Eicher and Jeff Kanipe

Fort Davis, Texas — Although it isn't known as the mecca for telescope builders, as Riverside is, the Texas Star Party does attract a healthy number of innovative, homebuilt telescopes. This year's most impressive telescope was brought by a member of the Houston Astronomical Society. Dewey Burkes' trailer-mounted 16-inch telescope, a conglomeration of aluminum and rivets, resembled a sizable antiaircraft gun. Dewey spent forty years operating a machine shop in Pasadena, Texas, and this telescope, over two years in the making, is his proudest achievement.



Below: Jeff Schroeder mounted his 11-inch refractor atop a station wagon. He ground, polished, and figured the objective lens.



Above: Robert Pfaff's fork-mounted 17-inch Newtonian doesn't wiggle in the wind.

Right: Mark Komsa exhibited his solid 10-inch reflector with homemade electric focusing at this year's Texas Star Party.

The instrument is mounted on an equatorial fork with a differential gear guiding system that, according to Dewey, is extremely accurate. The 16-inch full-thickness mirror operates as an f/4 Newtonian reflector with a rotating secondary mirror that reflects starlight to one of two eyepieces in the front of the tube. The telescope can also operate as an f/16 Nasmyth-focus Cassegrain using a plane mirror to divert light to an eyepiece through either side of the declination axis. Atop the telescope sits a 3.25-inch guidescope, its tube beautifully polished to a brilliant sheen. Now this telescope builder needs some help: "I've built the telescope," Dewey says jovially, "but I need someone to teach me how to use it."

Freon-Cooled Photo Rig

Not far from Dewey's telescope was an 8-inch f/1.5 Schmidt camera and a Celestron-8 in tandem on a single mount. The owner and builder of this homemade photographic setup is San Antonio's Robert Reeves, well-known for his spectacular photographs of the Milky Way (see "Exploring the Summer Milky Way," Photography in Astronomy, page 99 in this issue). Robert took a standard steel pier mount, attached a welded harness for the two scopes, and added electrically heated nichrome wire to prevent dewing of either corrector plate. To top this off, he drilled two holes into the Schmidt camera's tube and installed a system of rubber hoses and valves so that he can fill the camera with Freon, thereby cooling the film chips during exposures and reducing reciprocity failure.

Perhaps the most beautiful telescope on the field was not homemade but historic. Jack Eastman of Sheridan, Colorado, brought his 6-inch f/15 refractor made by the legendary firm of Alvan Clark & Sons. Built in 1877 in Cambridgeport, Massachusetts, this telescope was the property of Kentucky's Center College for several decades. It was acquired by a southeastern telescope dealer and was soon afterward purchased by Eastman. Although the seeing wasn't very good at this year's TSP, images of Saturn provided by the Clark impressed everyone who looked.

A Plentitude of Big Scopes

The fields at the Texas Star Party contained dozens of telescopes including many Newtonians and Schmidt-Cassegrains. Two dozen Dobsonians boasted mirrors larger than 16 inches. But the *real* show-stopper was a 24-inch f/4 Dobsonian built by David Higgins and friends from the Oklahoma City group. Higgins bought the mirrors, the focuser, and spider, but he built the rest of the scope from scratch. The design is pure and simple Dobsonian, but the execution is superb. The tube is a design made of aluminum struts and wood. To prevent stray light from entering the tube, Higgins stretches black cloth around the tube. The mirror cell has a protective cover that can be locked on to seal the mirror compart-

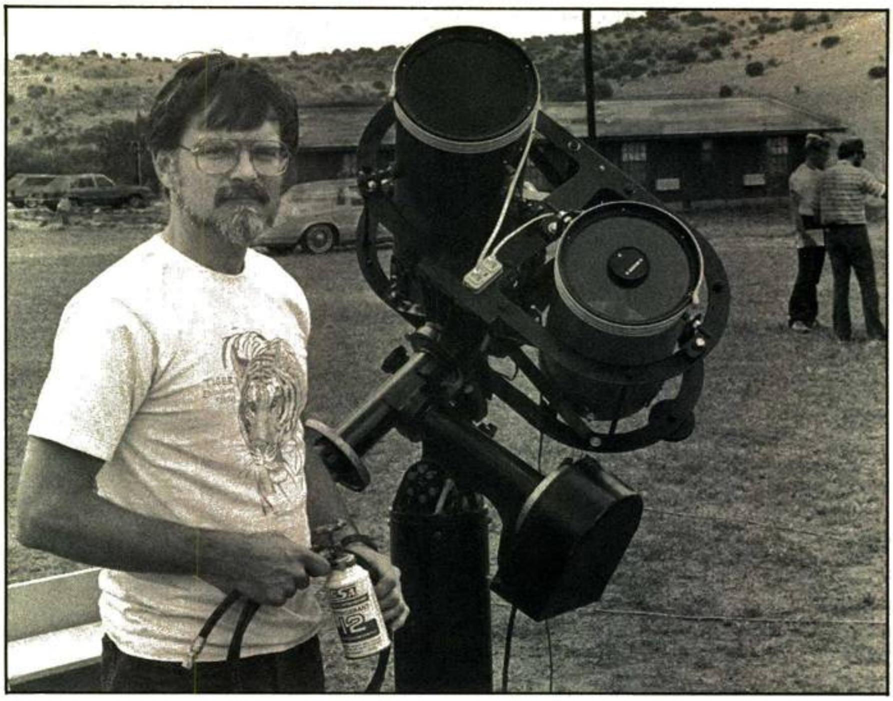
ment. The telescope's only unsophisticated feature was the secondary mirror cover — Higgins uses an old sock.

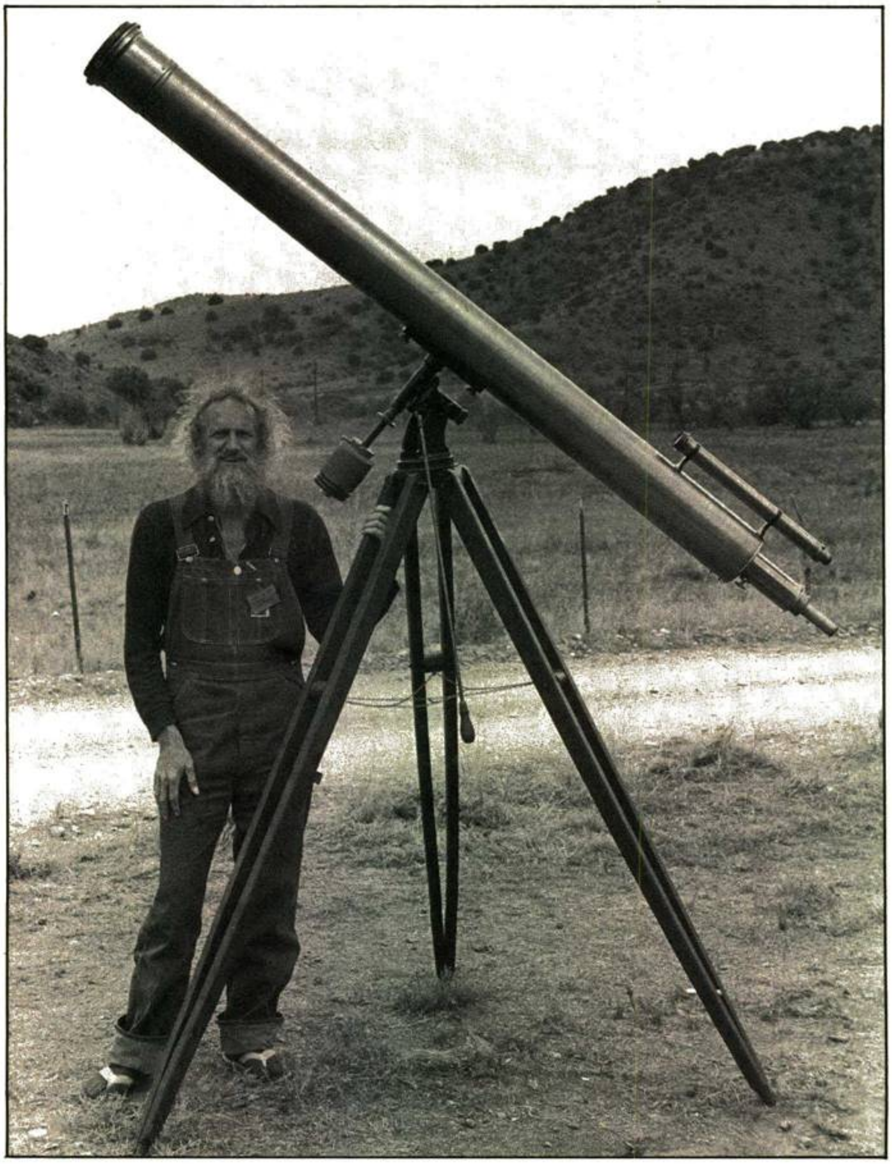
Observing the Great Omega

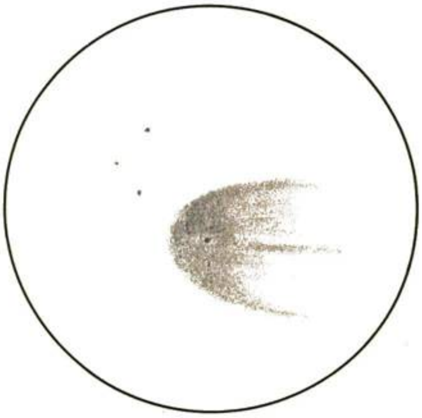
Observing is the main attraction at the TSP. On the first night of the TSP, as twilight ended and the sky darkened to blue-black, practically all the telescopes on the ranch aimed toward Omega Centauri, the giant globular cluster that has become the favorite object of TSP folks and a bit of a symbol for the star party. Many northerners, who can't see Omega when they're home, gasped in amazement when they saw the cluster through a large telescope.

At low power David Higgins' 24-inch telescope showed Omega as an oval-shaped globe of thousands of resolved stars. The cluster's bright, hazy core and "mottled" or "speckled" appearance caused by unresolved faint stars gave it an eerie, three-dimensional look.

Many observers moved their telescopes slightly north of Omega and saw NGC-5128, the giant lenticular galaxy also known as Centaurus A. Large scopes showed this object as a round ball of bright light bisected by a broad dust lane. Inside this dust lane were clumps of faint nebulosity, the light from huge stellar associations in front of the galaxy's dust lane.







Above: Designed and built by astrophotographer Robert Reeves, this cradle mount supports an 8-inch Schmidt camera and an 8-inch SCT for guiding. Reeves uses Freon refrigerant to cool his film.

Left: This 6-inch Alvan Clark refractor, built in 1877, was brought to the TSP by Jack Eastman of Sheridan, Colorado.

Below: Many observers at the TSP tried to find Comet Wilson as it peeked above the treetops toward the southwest after sunset. Barbara Wilson's sketch shows the comet as it appeared in a 13.1-inch telescope at 115x.

Talks at Texas

Strolling through the fields inspecting telescopes wasn't the only daytime activity. Amateur and professional astronomers presented talks on everything from the botched 6-meter Russian telescope to the *Galileo* mission to Jupiter.

Thursday afternoon Dan Brocious of the Fred Lawrence Whipple Observatory south of Tucson, Arizona, gave a fascinating talk on the woeful history of the Soviet 6-meter telescope. Located in the Caucasus Mountains in the southern part of the Soviet Union, it is the largest telescope in the world but remains virtually useless as a research instrument. The 350-ton monolithic mirror takes three days to thermally stabilize, so the figure is always changing. Most modern large mirrors are honeycombed in back so the reflective surface is only one or two inches from the air on the honeycombed side. This ventilates the surface and makes the mirror stabilize rapidly to changing temperatures.

The Soviets recast their mirror three times. The first mirror, which took two years and sixteen days to produce, cracked as it was cooling. The second mirror was mounted for the dedication ceremonies but was not figured well and therefore useless. Supposedly there are problems with the third mirror too, and some American astronomers have even speculated that a fourth mirror will be cast. Even the site atop 6,000-foot Mount Pastukhov is plagued with bad seeing and poor weather.

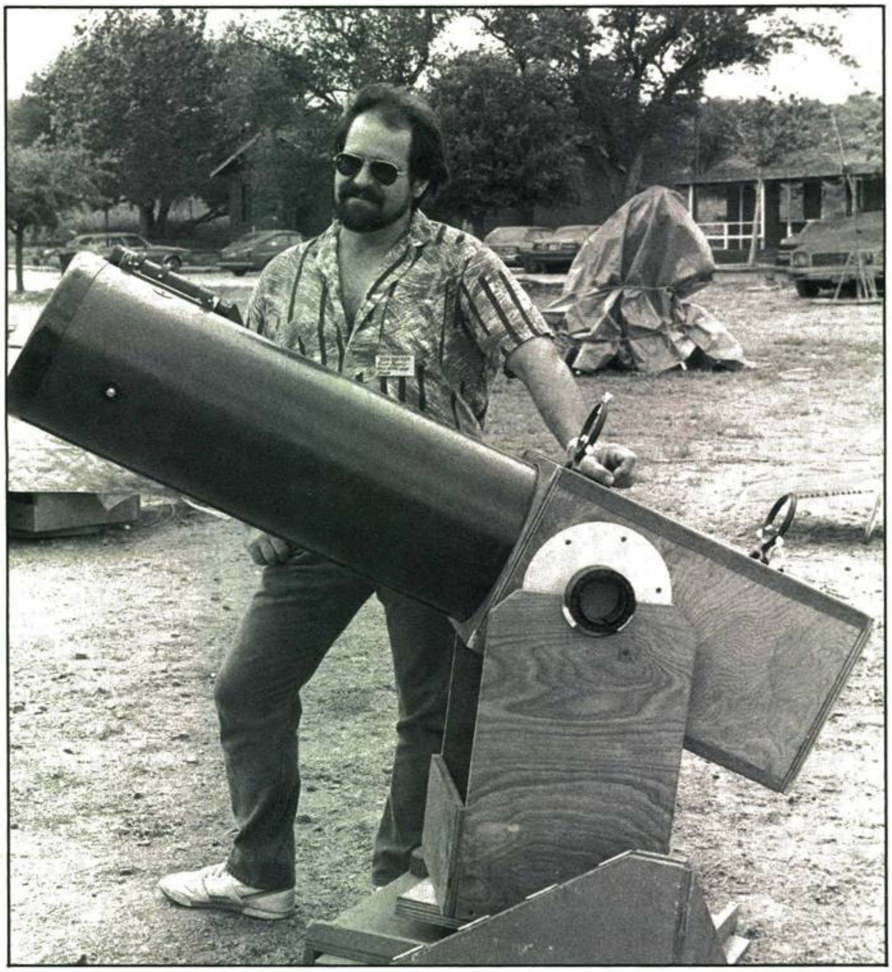
On Friday evening Curt Anderson from New Mexico State University laid out plans for the 3.5-meter telescope to be built on the 9,200-foot summit of Apache Point, a half mile south of Sacramento Peak in New Mexico. Anderson, the associate director of the project activities for the new telescope, says the instrument will be computer controlled and capable of remote operation. Construction has already begun on the site.

The Original Plutocrat

The highlight of the TSP lectures was the talk by Clyde Tombaugh, discoverer of Pluto, on Saturday evening. Tombaugh related the story of how he discovered the ninth planet, as well as how the discovery affected his career and his life. Anyone who has ever heard Tombaugh speak or who has read about how this Kansas farm boy secured an assistant's job at Lowell Observatory in 1929 and then went on to discover Pluto after nearly a year of painstaking work can't help but feel inspired.

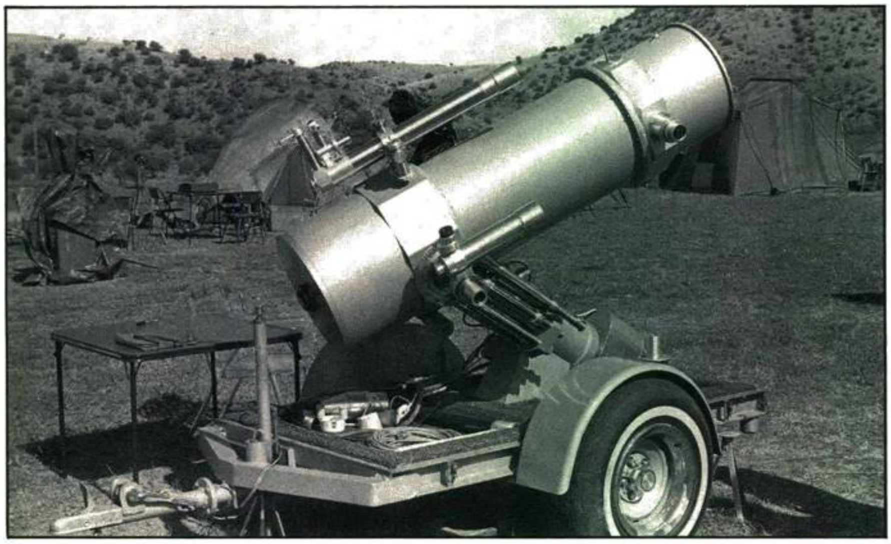
Later that evening Fort Davis astrophotographer Joe Liddell found Pluto, a tiny speck floating between two bright galaxies in Virgo. Many observers were awestruck at the notion of observing Pluto while Clyde Tombaugh made those awful puns he's known for just a few feet away.

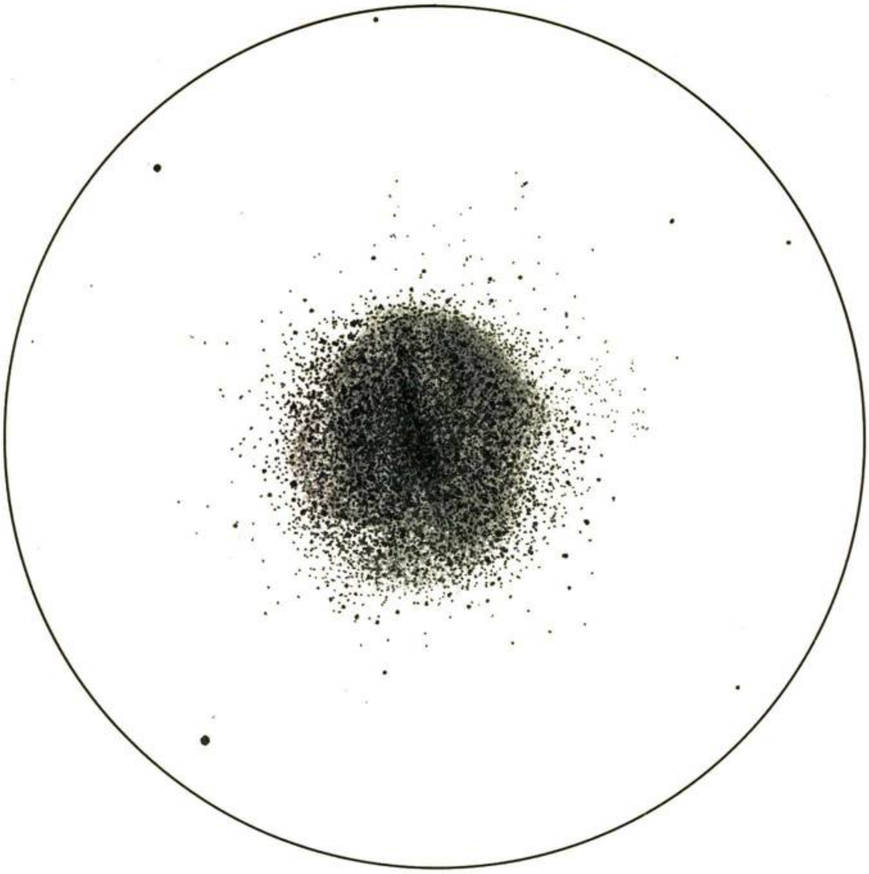
The telescope fields were dotted with people trying to do astrophotography this year. Although a number of astrophotographers were shooting through large telescopes, the method of choice was the camera platform. These simple devices allow you to take beautiful shots of star clouds or extended objects such as the North America Nebula with just a camera and a tripod. You don't need to drag along a telescope and mount for piggybacking. The rapidly changing weather at the TSP showed how very useful a platform's por-



Left: One of the best low-tech scopes was a 10-inch f/5.6 instrument built by Rick Harris of Oklahoma City. The equatorial platform under the telescope provides about twenty minutes of accurate tracking before it must be reset.

Below: This year the TSP's high-tech scope was Dewey Burkes' 16-inch combination f/4 and f/16 Newtonian/Cassegrain scope mounted on a trailer. Burkes, an engineer and mechanical tinkerer from Houston, spent two years building this instrument.

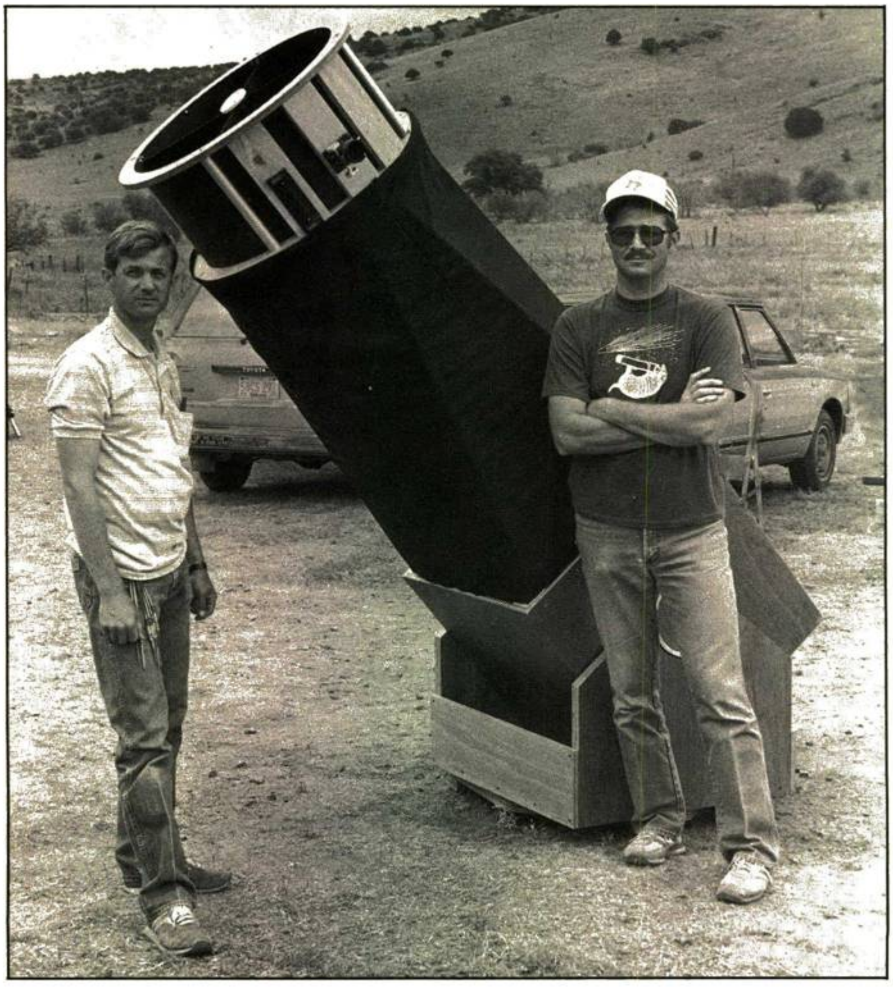




Above: Nearby McDonald Observatory was the daytime attraction at the TSP.

Left: The favorite object at the TSP and the first thing everyone looked at each night was globular cluster Omega Centauri. This sketch of Omega was made with a 17.5-inch f/4.5 reflector at 63x. Sketch by David J. Eicher.

Bottom left: The largest scope at the star party was David Higgins' (right) and Phillip Scott's 24-inch f/4 Dobsonian, brought to Texas from Oklahoma City.



tability, quick setup (and take down!), and ease of operation really are.

Difficult Weather

Unfortunately this year's TSP may go down in history as having the worst sky conditions for astrophotography since the Star Party began six years ago. Even when the sky was clear, it was filled with a bluish glow like the first light of dawn. In wide-angle photos the glow washed out contrast and made photos appear as if they had been shot through the glow of a fairly large but distant city. That didn't stop the observers, of course, and it didn't stop the astrophotographers either.

Despite the glow it's hard to deny the kernel of truth behind the motto of the TSP: "The observin's great in the Lone Star State." Or maybe it's because "the stars at night are big and bright deep in the heart of Texas."

Stretching from Cepheus through Centaurus, our Galaxy's disk appeared as a remarkably detailed, fluid painting, softly shimmering in contrast to the sharply defined stars peppered through it.

It was good to stop from time to time, forget all the telescopes and cameras and technical talk, and just gaze into the heart of the Galaxy, listen to the buzz of conversation, and know that this is what the Texas Star Party is all about.

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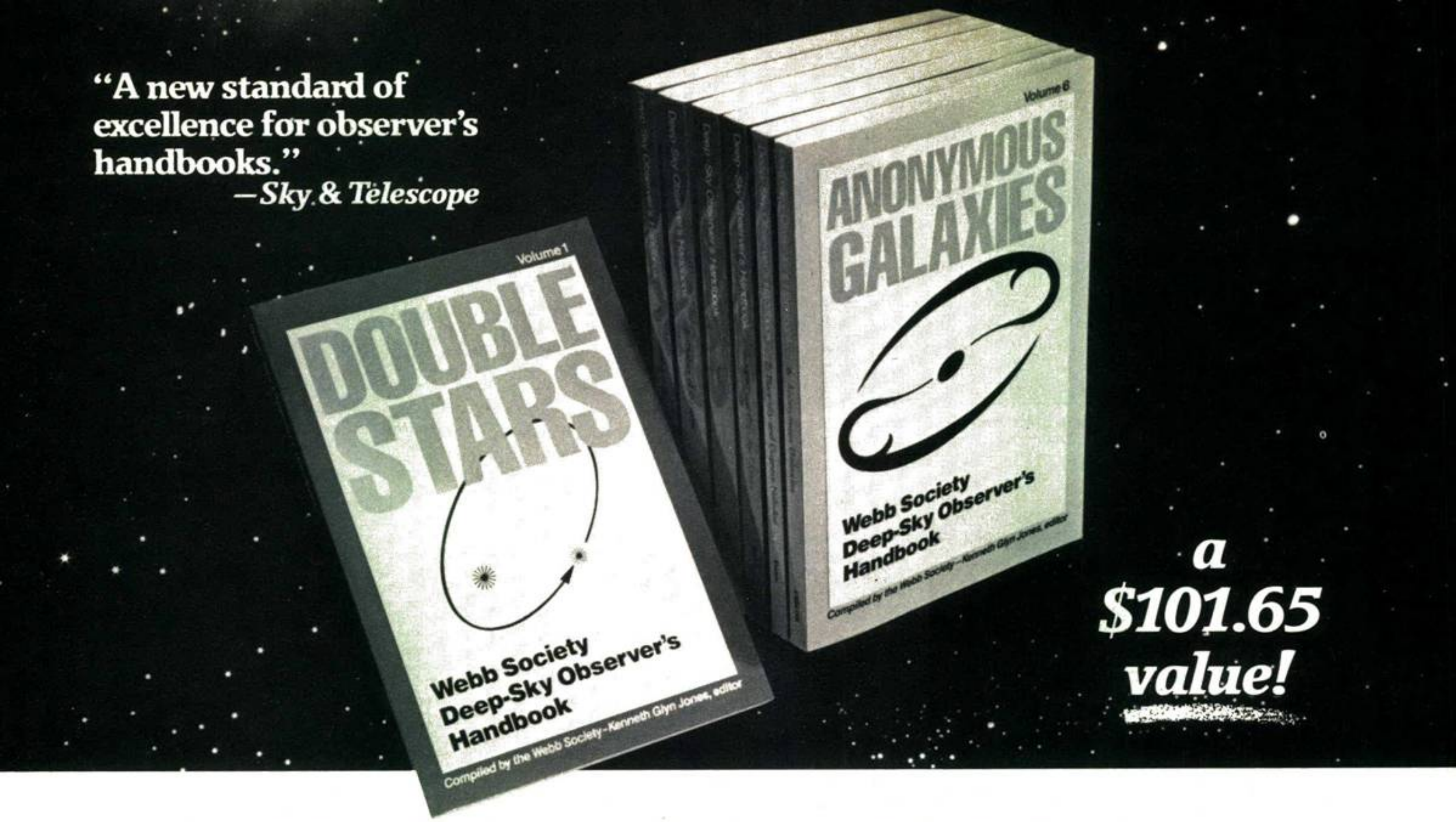
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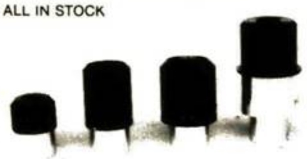
ASTROPHOTO OF THE MONTH

Spiral Galaxy M-99 (NGC 4254) in Coma Berenices. Spiral structure detail can be seen visually for this 10th magnitude galaxy. 40 minute photo by Dr. Jack Marling using hypered 2415 film, 24'' f/6 telescope and LUMICON Giant EASY-GUIDER.

20mm NAGLER

Also new 12mm & 16mm NAGLERS
TELE VUE™ EYEPIECES
USE THE BEST!!

ALL IN STOCK



Renaissance 4'' f/5.5. Telescope	$1395
7.4, 10.4, 13, 17, 21, 26mm Plossl, 50°	**$89**
1.8X or 2.5X Tele Vue Barlow Lens	**$89**
32mm Plossl, widest true field in 1¼''	**$109**
55mm 2'' Plossl, widest possible field	**$190**
15mm Wide-Field, 1¼'' eyepiece, 65°	**$129**
19mm Wide-Field, 1¼'' eyepiece, 85°	**$139**
24mm Wide-Field, "superb," 65°	**$159**
32mm Wide-Field, 2'' eyepiece, 65°	**$229**
40mm Wide-Field, "awesome," 65°	**$289**
4.8mm Nagler, 82° field	**$149**
7mm Nagler, 1¼'' eyepiece, 82° field•	**$185**
9mm Nagler, 82° field, "the best"	**$219**
11mm Nagler, 82° field, 1¼'' or 2''	**$235**
13mm Nagler, 82° field, 1¼'' or 2''	**$249**
12mm Nagler, type II, 82°, 1¼''/2''	**$249**
16mm Nagler, Type II, 82°, 1¼''/2''	**$299**
20mm Nagler, Type II, 82°, 2'' only	**$340**

Upgrade to 48mm filters! All are multicoated

UV, Green, Yellow, Orange, Red	**$18 each**
48mm H-Alpha Pass (640nm cut-off)	**$35**
48mm Minus Violet (420nm cut-off)	**$29**
48mm High perform blue, 90% trans	**$35**
Central Star Filter (blue tri-color) 340-470nm bandpass	**$35**
UV-370 U-Band, 320-420nm bandpass	**$35**
48mm Polarizer (2 make variable density)	**$18**
Set 9 ea. 48mm filters ($259 list)	**$195**
2''/1¼'' adapter threaded for 48mm filters	**$20**

H-ALPHA PASS FILTER

Yields spectacular contrast gains in B&W photography with telephoto lenses. Yields pinpoint star images. Superb with hypered 2415. For color, use the Minus Violet (MV) Filter.

Specify Lens Size	**H-Alpha**	**(MV)**
46, 48, 49mm	**$35.00**	**$29.00**
52, 55, 58, 62mm	**$45.00**	**$35.00**
67, 72, 77mm	**$52.00**	**$45.00**
82mm	**$55.00**	

Hypered 2415 film, 36 exp . . . **$10.95** . . . **3/$29**

LUMICON®

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For phone orders please call (415) 447-9570
LUMICON Products catalogue $2.
Foreign orders add 6% ($8 minimum)
California Residents add 6% tax.
Prices subject to change w/o notice
Hrs: M-F 9am - 5pm; Sat 11am - 3pm

NEW! ENHANCED SILVER DIAGONAL MIRRORS BOOST TELESCOPE PERFORMANCE

LUMICON 1.3'' & 2.1'' enhanced silver diagonal mirrors & 1¼'' star diagonal.
The new LUMICON diagonal mirrors have a special enhanced silver coating with a protective overcoating for long life. Visible reflectivity is 98-99% compared to 86-89% for standard aluminum coated mirrors. The extra 10-12% transmission is like adding an inch of aperture! The substrate is fine annealed Pyrex flat to 1/8 wave

1.32''	**$29.95**	1.52''	**$34.50**	1.83''	**$39.50**
2.14''	**$49.50**	2.60''	**$65.00**	3.10''	**$89.50**
4.25''	**$149.50**				

ENHANCED SILVER STAR DIAGONAL

90° star diagonals with above enhanced silver mirrors in a CNC machined black anodized aluminum body. Performance far exceeds prism diagonals.

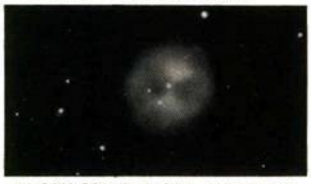
1¼'' (1.32'' mirror)	**$89.50**
2'' (1.83'' mirror)(see photo above)	**$145.00**

LUMICON FILTERS STOP LIGHT POLLUTION

UHC Filter™

ULTRA HIGH CONTRAST

The **LUMICON UHC FILTER** is specially designed for visual astronomy in areas of severe light pollution or for viewing very faint nebulae at any location. **UHC** stands for **U**ltra **H**igh **C**ontrast and this filter is guaranteed to yield a higher visual contrast on planetary and emission nebulae than any other filter at any price. 24nm visible bandpass, 482-506nm. Transmission = 85-95%.



"I CAN SEE THE OWL NEBULA!"
Tom Kramer saw the Owl Nebula, M-97, for the first time using a LUMICON UHC Filter. He stated, *"I had never seen M-97. . . I attached the UHC Filter and tried again. M-97 was right there. I could not believe it! The UHC Filter should be standard equipment."* **Tom Kramer, Sayville, NY**

For optimum astronomy, use either the **LUMICON DEEP-SKY Filter** or the **LUMICON UHC Filter**

DEEP-SKY FILTER™

The **LUMICON DEEP-SKY FILTER** improves your view of **all** deep-sky objects including galaxies and comets. It removes natural and man-made light pollution and yields 3-6x contrast gain for nebulae and 1-3x contrast gain for clusters and galaxies. It is ideal for **both** visual use and B&W or color photography. This gentle filter yields the most natural view of any LPR filter available today. 90nm visible bandpass. 442-532nm. H-Alpha 656nm transmission = 85-95%. Visible transmission = 90-95%.

	Standard	**Premium***
0.96'' LUMICON DEEP-SKY Filter threads into most 0.96'' eyepieces		**$59.50**
1¼'' LUMICON DEEP-SKY Filter threads into most 1¼'' eyepieces		**$79.50**
48mm LUMICON DEEP-SKY Filter (1.75'' aperture), threads into most 2'' eyepieces. Also fits LUMICON EASY-GUIDERS		**$119.50**
2'' LUMICON DEEP-SKY Filter (1.5'' aperture), threads into most 2'' eyepieces. Also has male & female camera T-threads for prime focus photography	**$99.50**	**$119.50**
72mm LUMICON Giant DEEP-SKY Filter (62, 67, 77mm adapter, $8)		**$299.50**
1¼'' LUMICON UHC Filter threads into most 1¼'' eyepieces	**$79.50**	**$99.50**
48mm LUMICON UHC Filter (1.75'' aperture) fits most 2'' eyepieces	**$159.50**	**$199.50**
Set of Both 1¼'' **DEEP-SKY** and **UHC Filters** (Save 11%)		**$159.50**

LUMICON H-BETA Line Filter (9mm bandpass at 486nm). For the California Nebula, Horsehead Nebula, and other extremely faint nebulae. .... **1¼'' $89.50** **48mm $189.50**

Oxygen-III Filter for very faint planetary and diffuse nebulae, 11nm bandpass at 496nm and 501nm 0-III lines .... **1¼'' $99.50, 48mm $199.50**

Telephoto lens adapter for 2'' or 48mm filter. Select 46, 49, 52, 55, 58mm	**$6.95**
Universal adapter for 1¼'' filters. Adapts the 1¼'' filters to any 1¼'' eyepiece	**$16.00**
Universal adapter for 48mm or 2'' filters. Allows use of any 1¼'' eyepiece	**$20.00**

**Premium filters are selected best of the lot and typically have 5-10% higher transmission. Not always available. Include individually measured transmission data.*

DEEP-SKY ASTROPHOTOGRAPHY

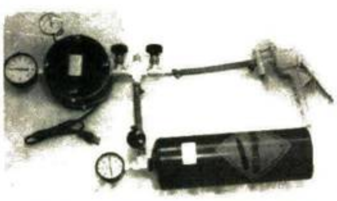
FILM HYPERSENSITIZATION KITS†

LUMICON HYPER-KITS™ yield 3-15X film speed gain in long exposures. They are safe & simple to use. Easy HYPER-KIT includes a chamber with all controls and fittings, thermometer, a refillable cylinder of non-flammable forming gas & hand-operated vacuum pump.

U.S. Patent 4,473,636

MAKE YOUR OWN HYPERED FILM

MODEL 300 HYPER-KIT sensitizes any 35mm film in hours. Best for 2415. Achieves highest possible film speeds **$295.00**



MODEL 600 HYPER-KIT [See Photo] Like the Model 300, but also sensitizes 120/220 larger format film and small glass plates **$350.00**

MODEL 1200 HYPER-KIT is for 4X5'' plates and film up to 5X7'' Has 2 gas cylinders and includes temperature controller .. **$595.00**

Temperature controller for any HYPER-KIT **$59.50**

Electric Vacuum Pump, Model R-10 **$280.00**

GUIDE OFF-AXIS FOR LOVELY ASTROPHOTOS

All **LUMICON EASY-GUIDER™** off-axis guiders† have both radial and 360° rotational adjustments for 5X eaiser guide-star selection, use 48mm filters, 360° camera rotation, large prisms fo bright guide-starts. *Specify Camera and Telescope type.*
U.S. Patent # 4,448,500

NEWTONIAN EASY-GUIDER™

Full aperature. Installs in secs. Specify 2'' or 1¼''.

NEWTONIAN EASY-GUIDER	**$169.50**
3X Relay Diagonal (see photo)	**$79.50**
Illuminated reticle eyepiece system	**$89.50**

Guider for Hasselblad **$350,** Mamiya 645 **$199**

CASSEGRAIN EASY-GUIDER™

For C-8, Meade 2080, Dynamax-8. Includes 50mm achromatic lens for f/5.8 operation-3X shorter exposures! **Superb rich field viewing, too!**

CASSEGRAIN EASY-GUIDER **$225.00**
Adapter for Hasselblad **$185,** Mamiya 645 **$159**

GIANT EASY-GUIDER™

For Celestron-11, C-14, and the 10'' Meade 2120. Includes 80mm clear aperture achromatic lens for edge-to-edge illumination & pin-point star images. F-ratio adjustable f/4-f/11. **Also yields unmatched Rich-Field viewing.**

GIANT EASY-GUIDER **$395.00**
48mm DEEP-SKY Filter ordered with any EASY-GUIDER (SAVE $20) ...... **add $99.95**
Adapter for Hasselblad **$195,** Mamiya 645 **$96**

WHAT DO YOU NEED?

1. Illuminated reticle eyepiece **$89.50**
Lumicon 12mm eyepiece system has adjustable L.E.D. illumination, dual crosslines, battery pack.
2. Cable release for long exposures .. **$9.95**

3. **LUMICON Quartz Drive Corrector $219**
Dual-axis drive corrector is essential for astrophotography and/or field use of your telescope. 40Hz/80Hz variable output controls telescope drive. 60Hz Quartz reference ±12VDC Declination control output. Both 110VAC and 12VDC input for home or field use. Declination reverse switch for Newtonians.

Declination motor (state telescope) .. $70
NEW Deluxe Digital Qtz. Drive Correc. **$298**

HYPERSENSITIZED FILM

LUMICON Hypersensitized film is essential for good deep-sky astrophotography. Deduct 10% for 3 or more rolls (mixed o.k.).

Film Type, 35mm	**Exposures**	**Price**
2415, Ultra-fine B&W, red sens.	36	**$10.95**
SR1600, fastest of all, color neg	24	**$12.95**
Konica SR200, fine grain color neg	12	**$9.95**
3M 1000, fastest slide film	20	**$12.95**
Fujichrome RD100, fine grain slide	24	**$12.95**
5072, color slides from neg	36	**$6.95**
D-19 B&W Developer	1 gal.	**$6.95**

NEW LUMICON® PRODUCTS

LUMICON, 2111 Research Dr., #5
Livermore, CA 94550 (415) 447-9570

NEW! NON-ROTATING HELICAL FOCUSER

LUMICON® DELUXE NON-ROTATING HELICAL FOCUSER on a 6" telescope.
LUMICON has just designed a deluxe smooth helical focuser with non-rotating 2" i.d. eyepiece holder. It has a vertical travel of 1¼" and a very low profile only 1½" high. It is CNC machined, black anodized, and a perfect match to LUMICON EASY-GUIDERS.

Select your desired base-plate shape! Flat, 7" OD, 9½" OD, 12½" OD, 16" OD, 20" OD, SUPER-FINDER base plate.

LUMICON Deluxe Helical Focuser	**$79.50**
3 handles (see photo)	**$12.95**
Helical focuser with 3 handles	**$92.40**
2"/1¼" adapter w/48mm filter threads	**$20.00**
2" LUMICON EASY-GUIDER	**$169.50**

EYEPIECE PROJECTION

These adapters allow high magnification photography of the Moon and Planets using eyepiece projection. The may be used without any eyepiece for prime-focus photography. All adapters use standard camera T-rings.

Tele-Extender for Meade or Celestron SCT.	**$32**
1¼" Basic Camera adapter, 2 part system	**$32**
0.96" Basic Camera adapter, 2 part system	**$32**
1¼" prime Focus adapter, fits 1¼" focuser	**$22**
0.96" prime Focus adapter, fits 0.96" focuser	**$22**
Camera T-ring, specify 35mm camera type	**$12**

LUMICON 80mm SUPER-FINDER™

Visual Astronomers prefer the LUMICON SUPER-FINDER™, since hundreds of deep-sky objects, including most Messier objects, are visible directly. SUPER-FINDERS also make nice small portable telescopes. 80mm aperature, F=300mm coated achromat. The deluxe SUPER-FINDER uses an 80mm, F=500mm air spaced achromat.

1¼" straight-thru SUPER-FINDER	**$169**
1¼" right-angle version, w/star diagonal	**$195**
2" right-angle version, non-rotating focuser	**$199**
1¼" Deluxe right-angle Super-Finder	**$279**
2" Deluxe right-angle Super-Finder	**$309**
25mm Cross-hair 1¼" eyepiece (12X)	**$29**
1¼" Star Diag. **$32**, 2" Star Diag., silver,	**$145**

2" ADAPTERS MEADE, CELESTRON TELESCOPES

These adapters convert refractors and Schmidt-Cassegrain telescopes for 2" operation. They allow use of 2" accessories, such as the LUMICON 2" EASY-GUIDER for photography. They also allow use of 2" eyepieces and/or 2" star diagonal for viewing.

2" adapter for C-8, Meade 2080, etc.	**$26.00**
2" adapter for Criterion 4000, 8000	**$26.00**
2" adapter for C-80, C-90, C-100	**$39.50**
2" adapter for C-70, C-80F, C-90F, C-100F	**$39.50**
2" Accessory adapter for Comet Catcher*, C-6*, Meade 310, 320 refractor	**$30.00**

* will not reach focus with 2" EASY-GUIDER™, use 1¼" LUMICON EASY-GUIDER for astrophotography.

ASTRONOMER'S LED FLASHLIGHT

Two flashlights in one! A red LED (light emitting diode) is ideal to read star maps and preserves your eye's dark adaption. A brighter green LED help you to find things in the dark. No bulb to burn out, 3 AA batteries last many months.

Starlight™ LED Flashlight **$14.95**

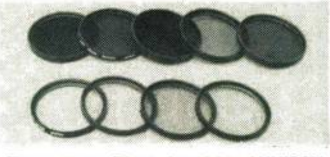
VIEWING ADAPTERS

2"/1¼" Adapter, threaded 48mm filters	**$20**
2"/1¼" Adapter, unthreaded	**$12**
2"/T - Thread adapter, threaded 48mm	**$25**
T - Thread/1¼" adapter. Converts telephoto lenses for viewing as finderscopes	**$25**

EXTENSION TUBES

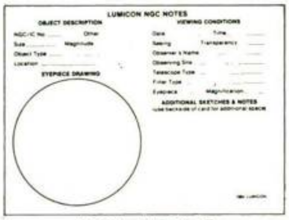
1.0" long Thread-in extension tube	**$12.00**
1-2½" long, threaded for 1¼" filters	**$16.00**
4½" long extension tube, 1¼" i.d.	**$25.00**
2" i.d. Extension tube, 3" long, threaded for 48mm filters, adds 1.6-3.0"	**$26.00**

48mm COLORED GLASS FILTERS



These 48mm Filters thread into LUMICON EASY-GUIDERS and most 2" eyepieces. Use adapter for 1¼" eyepieces. AR Coated.

Filter:	**Bandpass,**	**Trans,**	**Price**
Ultraviolet	320-420nm,	85%,	**$35**
UV	380nm-IR,	98%,	**$18**
Minus Violet	420nm-IR,	96%,	**$29**
Blue Tricolor	340-470nm,	80%,	**$35**
Hi Perf. Blue	300-540nm,	95%,	**$35**
Yellow	480nm-IR,	98%,	**$18**
Green	490-590nm,	60%,	**$18**
Orange	560nm-IR,	98%,	**$18**
H-Alpha Pass	640nm-IR,	95%,	**$35**
Cyan	340-580nm,	95%,	**$59**



LUMICON NGC NOTES
OBJECT DESCRIPTION
VIEWING CONDITIONS
EYEPIECE DRAWING
ADDITIONAL SKETCHES & NOTES

NGC NOTES

These handy **NGC NOTES** are stiff 4"X5½" cards. the **NGC NOTES** fit in your hand and are ideal for making notes and sketches while observing at the eyepiece. Making sketches **greatly improves** your observing skills and also gives you a permanent record. Get 200 **NGC NOTES** for Messier objects; NGC object observers should get 400-800 **NGC NOTES.**

NGC NOTES, Pack of 200 .... **$9.95**
Pack of 400 **$17.95** Pack of 800 **$32.95**

Meade® TELESCOPES AT LUMICON

NEW! MEADE 2080/LX5 ..... $1795
MEADE 2120/LX5 .... $2695

The most advanced Schmidt-Cassegrain telescope available! *Standard equipment* includes dual-axis hand-held electronic command center, 2" mirror star diagonal, 9X60mm polar viewfinder, multi-coated/enhanced optics, 26mm Super Plossl, tripod and wedge.

#39 Electric declination for 2080 or 2120/LX5	**$109**
Dew shield-essential 8" (#712) **$65**; 10" (#710)	**$98**
Accessory shelf for field tripod ($40 list)	**$28**
LUMICON EASY-GUIDER/Rich-Field viewer: for 2080 (f/6 operation) **$225**; for 2120 (f/4-f/10 operation)	**$395**
Computer control system, 8000 object memory	**$1495**

Meade 8" Model 2080/LX5: Shown with *standard-equipment* 9X60mm finder, dual-axis controller, 2" Diagonal Mirror, Equatorial Wedge, Field Tripod.

10" Meade 2120/GEM ONLY $1799

Meade 2120/GEM (left) and 8" 2080/GEM Schmidt-Cassegrain optics on German Equatorial Mount.

2080/GEM, 8" f/10 w/MCSO, equatorial mount	**$998**
2120/GEM, 10" f/10 w/equatorial mount	**$1799**
2120/GEM, 10" f/10 w/MCSO, equatorial mount	**$1949**
Dew shield & accessory tray, 8" **$72**; 10"	**$144**
#784 Motor & quartz drive corrector ($310 list)	**$219**
Computer Control system, 8000 object memory	**$1495**
Solar Filter for 2080 ... **$149**; for 2120	**$185**

4" MEADE 2045 w/table tripod $595

4" f/10 Meade 2045/LX3 w/quartz drive	**$795**
#36 dual-axis cont. (LX3) **$99**, #38 dec. motor	**$99**
Wedge & field tripod for Meade 2045 ($380 list)	**$298**
Dew shield ($80 list) .. **$55**; Solar Filter	**$95**

FILTERS STOP POLLUTION

LUMICON UHC Filter for nebulae. Standard 1¼"	**$79**
Prem 1¼" **$99**; Std 48mm **$159.50**; Prem 48mm	**$199.50**
LUMICON Deep-Sky Filter, 1¼" Premium	**$79**
48mm Prem Deep-Sky **$119.50**, **$99.95** w/Easy-Guider	
Adapter for viewing w/1¼" eyepiece	**$20**

PHOTOGRAPHY ACCESSORIES

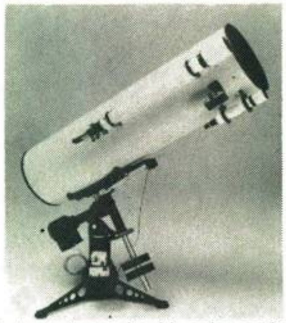
LUMICON Newtonian Easy-Guider, 1¼" or 2"	**$169**
LUMICON Cassegrain EASY-GUIDER for Meade 2045, 2080/LX5 and 2080/GEM (state camera)	**$225**
Illuminated reticle eyepiece & battery pack	**$89.50**
Dual-axis Drive corrector	**$219**

These Meade Telescopes are complete and ready for viewing.

They include telescope with all coated optics for high transmission, mount, tripod or pier with legs, motor drive (except models 6600, 8800, GEM series). Finderscope, at least one eyepiece, and complete instructions. Call or write LUMICON for full technical information. MCSO means multi-coated silvered optics.

MEADE NEWTONIAN TELESCOPES

16" f/4.5
MEADE
DS-16A
only
$1975



Note: Astrophotographers should order optional sealmaster ball bearings for the DS-16A (add $229).

Model 6600, 6" f/5 w/1¼" focuser, 6X30 finder	**$685**
Model 628c, 6" f/8 w/motor, 2" focuser, 8X50 finder	**$798**
Model 645c, 6" f/5 w/motor, 2" focuser, 8X50 finder	**$829**
Model 8800, 8" f/4.5 w/1¼" focuser, 6X30 finder	**$895**
Model 826c, 8" f/6 w/motor, 2" focuser, 8X50 finder	**$975**
Model DS-10A, 10" f/4.5 w/motor, 2" focuser	**$995**
Model DS-16A, 16" f/4.5 w/motor, 2" focuser	**$1975**
Sealmaster ball bearings for DS-16A, recommended!	**add $229**
Finderscope for DS-10A, DS-16A, 8X50mm right angle	**$126**

All foreign orders add 6% ($8 minimum). California residents add 6% tax. Prices subject to change w/o notice. Set Meade and LUMICON Catalogues $4. **LUMICON, 2111 Research Dr., #5, Livermore, CA 94550.** Call **(415) 447-9570** for information & orders. Store Hours: M-F 9am-5pm; Sat 11am-3pm. All telescopes shipped F.O.B. Livermore.

ASTRONOMY

In Focus

Clearing Skies over Cleveland

Sir / I found the article "Cloudier Skies in the Forecast?" (AstroNews, July 1987) very interesting, because I have been keeping a record of clear evenings and mornings in Cleveland, Ohio, since the beginning of the year.

The ground rules I've used for a clear sky in my records are a light haze or some cirrus clouds and good conditions from sunset until midnight or from 5 a.m. until dawn. (Under these conditions I could still use my 8-inch Schmidt-Cassegrain or my 10x50 binoculars for some worthwhile observing.)

I also checked with the National Weather Service to see how it keeps records. The NWS keeps records from sunrise to sunset, taking observations every hour to determine sky conditions by percentage of cloud cover. Zero to 3/10ths cloud cover is considered clear, 4/10ths to 7/10ths is partly cloudy, and 8/10ths to 10/10ths is cloudy. The NWS also takes observations at night, but this data is not part of the daily records.

Through the end of May I have recorded fifty-seven clear evenings and fifty clear mornings, which works out to just over ten clear evenings per month. I'm interested in hearing from other clubs that are keeping records similar to those of my club.

If the skies are getting cloudier across the country, I'm glad the evenings are clearing up in Cleveland!

Marty Mayer
Cleveland, Ohio

Portable Platform Improved

Sir / I have been using a simple photographic mount like the one described by Wallace G. Pursell in "A Portable Photographic Platform" (Equipment Atlas, July 1987) for years — with excellent results — and was pleased to see the mount presented in your magazine.

G. Y. Haig of Scotland first conceived of the portable photographic mount in 1975, and numerous refinements have been made by others since then. Astrophotographers Dick Suiter of Panama City, Florida, and John Kerns of Los Angeles, California, introduced me to an improved version of the mount in 1980.

Here are a few additional tips for using the mount.

1. Exposures of up to 20 minutes are possible — though those of 10 to 15 minutes are more realistic — before tracking errors become a problem.
2. Telephoto lenses up to 200mm may be used, though 135mm lenses are the more practical limit. Tolerances for error are 21 seconds with 28mm, 12 seconds for 50mm, 4.5 seconds for 135mm, and 3 seconds at the celestial equator.
3. Try to sight on the north celestial pole, not on Polaris.
4. Add extra weight for stability if necessary.

Willkie Cirker
Columbus, Ohio

Sir / I'd like to offer some variations on Wallace G. Pursell's portable photographic platform. If size and portability aren't that important to you, you can build a somewhat similar platform that stands on the ground and place the tripod with the camera on the platform. By increasing the hinge-to-drive bolt distance, the sensitivity can be decreased. This will allow you to use a "T" handle or a crank handle instead of a drum, which makes it easier to use in the dark because one-fourth or one-half turn can be made without a light. A hinge-to-drive bolt distance of 28.65 inches allows you to turn the drive bolt one-fourth turn every five seconds when using a drive bolt with 24 threads per inch.

Charles Klimitchek
Hallettsville, Texas

Quasar Hunting a Piece of Cake

Sir / John Mood's article "Star Hopping to a Quasar" (Gazer's Gazette, April 1987) was quite enjoyable. For years I've been tantalized by the idea of hunting down 3C 273, but finding its 13th-magnitude image among so many faint stars was discouraging.

My area of southern New Jersey has a light-polluted northern sky because of Camden and Philadelphia. Nevertheless, naked-eye stars are visible down to nearly 6th magnitude on the clearest nights. May 16 was one of those clear nights, and Mr. Mood's star-hopping procedure provided the final incentive to find 3C 273.

With a 10-inch Dobsonian and an 8x50 finder scope I quickly traversed through the star patterns. I got lost only once, and after backtracking, I easily found the small triangle of stars containing the quasar. At 13th magnitude the quasar was surprisingly easy to see. I now consider locating the quasar a "piece of cake."

Bob Schepis
Mullica Hill, New Jersey

Keep Men on the Moon

Sir / There are advantages to building a permanent lunar base. While samples of rock and soil from Mars would be valuable, as Marc Edwards' letter states (In Focus, May 1987), in the long run a lunar base would be more valuable. What would the astronauts do after collecting samples except pack up and go home?

On the other hand, if we first build a colony on the Moon, we will gain experience in space construction. We would be able to send an expedition to Mars, not only to explore the planet but to set up a permanent base there. Once we have bases on the Moon and Mars, we could then move farther out into the solar system.

Abby Wilmarth
Council Bluffs, Iowa

Gear in Pockets

Sir / I've found an inexpensive way to keep my observing gear close at hand yet off the ground.

I purchased a carpenter's apron for doing work around the house and forgot to take the apron off one night when I went out to observe. The apron has proved quite useful for observing. I put my dust covers and eyepieces in the two large pockets, pens and pencils in a slot, and my observer's flashlight in the loop. The apron cost a couple of dollars and keeps my gear right where I need it.

Chuck Dessert
Hiddenite, North Carolina

'Michigan Spacelog' Available Only to News Media

Sir / The "Michigan Spacelog," which I mentioned in my letter on astronomy services to the media (In Focus, June 1987), is available *only* to news media, not to the general public. If you're interested in the service but are not with a news medium, the best service you can render to your community is lobbying your local media to subscribe to my column.

Jim Loudon
University of Michigan Exhibit
Museum of Natural History
Ann Arbor, Michigan

An Enemy of Science?

Sir / Rodney Schroeter's letter (In Focus, June 1987) claimed that Immanuel Kant was an enemy of science and made a "systematic attack on the mind of the man."

This is a misunderstanding of Kant. The limitations Kant put on human reason were precise. He said knowledge was limited to what could be verified by experience. Questions about the existence of God or man's immortal soul, which can never be verified by experience, can never be proved and must remain a matter of faith.

Kant also held that the questions about whether the world had a beginning in time and space and whether it is finite or infinite also could not be proved by experience.

Kant was far from being an enemy of science. He sought to protect science from skeptical attacks.

Martin Weatherston
Toronto, Ontario, Canada

Last View of Halley's Comet

Sir / I have been keeping my eye on Halley's Comet since the beginning — even before. The day the comet was recovered by the 200-inch telescope at Palomar Observatory, I was scheduled to spend the evening at the Multiple Mirror Telescope at Mount Hopkins, south of Tucson, to document the search for the famous visitor. Although I missed the chance to be one of the first three people to see the comet during this apparition, I have since tried to observe the comet whenever and wherever possible.

On the evening of April 24, 1987, I got a call from David Levy, who said that a mutual friend, Jim Scotti, had Halley's Comet in the eyepiece of a 16-inch telescope. David was using the 61-inch telescope of Steward Observatory, atop Mount Lemmon, with a CCD camera attached to image the faint comet. Though I was in the middle of an important project, David convinced me I would kick myself (more than once) if I didn't take this opportunity to see the comet.

When I arrived, Jim had the comet in the field. Sky conditions were far from ideal. After a few minutes of dark adaptation I thought I perceived an object that didn't quite look like a star. Jim had Polaroid pictures of the field from the Palomar Sky Survey, and these confirmed that what I saw was the comet. It kept fading in and out as cirrus clouds obscured the view. Jim estimated the brightness at apparent magnitude 13.5. We observed the comet for another half hour, until the clouds rolled in.

That may well have been my last view of Halley before the comet fades into invisiblity to all but electronic eyes.

Michael E. Bakich
Assistant Director
Flandrau Planetarium
Tucson, Arizona

Oops!

In the Night Sky diagram on page 48 of the August 1987 issue the Moon should have been represented in the waxing gibbous phase.

Behind the Scenes

Time Enough for Rings

Do you remember when *Voyager* flew by Jupiter and Saturn? Or did those flybys occur before *you* got interested in astronomy? Either way you're probably aware that *Voyager* scientists made many major discoveries in a short time.

The day after new images of moons and rings arrived on Earth, these images appeared in news media around the world. *Voyager* press conferences became circuses of "instant science" as the world focused on dazzling discoveries.

We learned obvious things instantly. Jupiter's colorful clouds and Saturn's multitude of rings were quick discoveries. The discovery of Jupiter's ring happened seconds after the image popped up on the video monitor.

Other discoveries and measurements took longer — diameters, densities, small moons searches, weather patterns velocities. Researchers stumbled onto Io's volcanoes a week after the flyby. "First-look" geological maps took a month to produce.

Progress in science takes time, but it proceeds with a certain inevitability. The thousands of images returned by the two *Voyager* spacecraft left planetary scientists stunned, confounded, and shaken by the unexpected complexity of the ring system. Pre-*Voyager* notions of how rings form and evolve would have to change.

Finding rings took hours. Counting them took days. Measuring their positions took months. Modeling them has taken years. Understanding them will take decades more.

Seven years after *Voyager* flew past Saturn, we're beginning to understand what its cameras saw. Data taken at Uranus offered fresh insights into the life history of ring systems.

But theories live or die by the facts.

If *Cassini* ever flies to Saturn, we will discover more facts. *Cassini's* high-resolution cameras will inevitably produce new "observational evidence," and the theories will have to deal with it. We will or won't find moonlets embedded in the rings. The F-ring will or won't have condensed into small moons. What we find when we go out there will test the theories the *Voyager* pictures spawned. The new results will raise new questions, spawn new theories, and provoke new speculations.

And slowly we will find the answers.

Sincerely,

Richard Berry

Richard Berry
Editor-in-Chief

Gazer's Gazette

The Secret World of Dark Nebulae

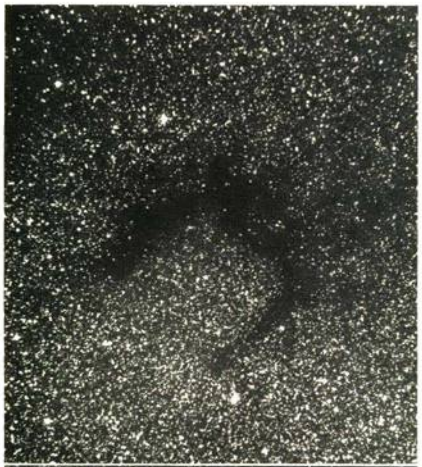
by David Higgins and David J. Eicher

If you walk outside and look up on a clear autumn night in suburbia, you'll likely see a few dozen bright stars. After dark-adapting your eyes for several minutes, you'll see hundreds of stars and, perhaps, a faint glow marking the Milky Way.

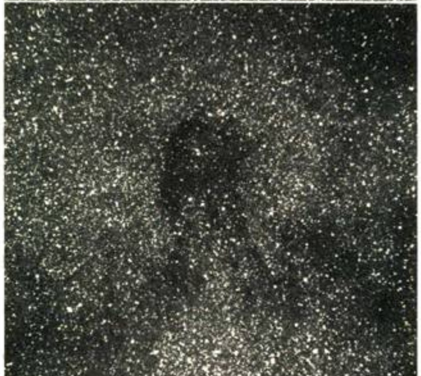
Walk outside under a black, rural sky, though, and the view is dramatically different. Against a sky full of stars you'll see a bright, detailed Milky Way that almost looks like an airbrush painting. Under these conditions you can see not only bright patches but dark clumps and filaments. These dark areas are dark nebulae, clouds of opaque dust grains in space that block starlight from behind.

Dark nebulae are not difficult to observe, provided your observing location and equipment meet a few basic requirements. Because dark nebulae are defined by bright objects surrounding them, the sky must be reasonably dark. Your telescope is an important consideration. The more aperture you have, the better: mirrors in the 12-inch or larger class reveal faint stars and therefore make seeing hundreds of dark objects possible. You don't need a large scope, however. Several dozen fine examples of dark nebulae are easily visible in binoculars or small telescopes under a dark sky.

The large, dark rifts in the Milky Way have been observed since antiquity. Telescopic dark nebulae, the smaller patches and lanes of cosmic dust that in groups form naked-eye dark nebulae, have been observed since the invention of large telescopes about two hundred years ago. In 1784 the English observer Sir William Herschel studied what is now called the Rho (ρ) Ophiuchi dust cloud near the bright star Antares. Herschel observed many lanes and patches where the overall star density was low relative to the surrounding starfields. Herschel couldn't determine the nature of dark nebulae, but he diligently cataloged many of these objects. A detailed study had to wait until photography revealed the full extent of dark nebulae.



Top: Dark nebulae are easier to see than you may think. B143 is an opaque, C-shaped cloud in Aquila.



Above: B87 in Sagittarius is known as the "Parrot's Head Nebula." Photos by Martin C. Germano.

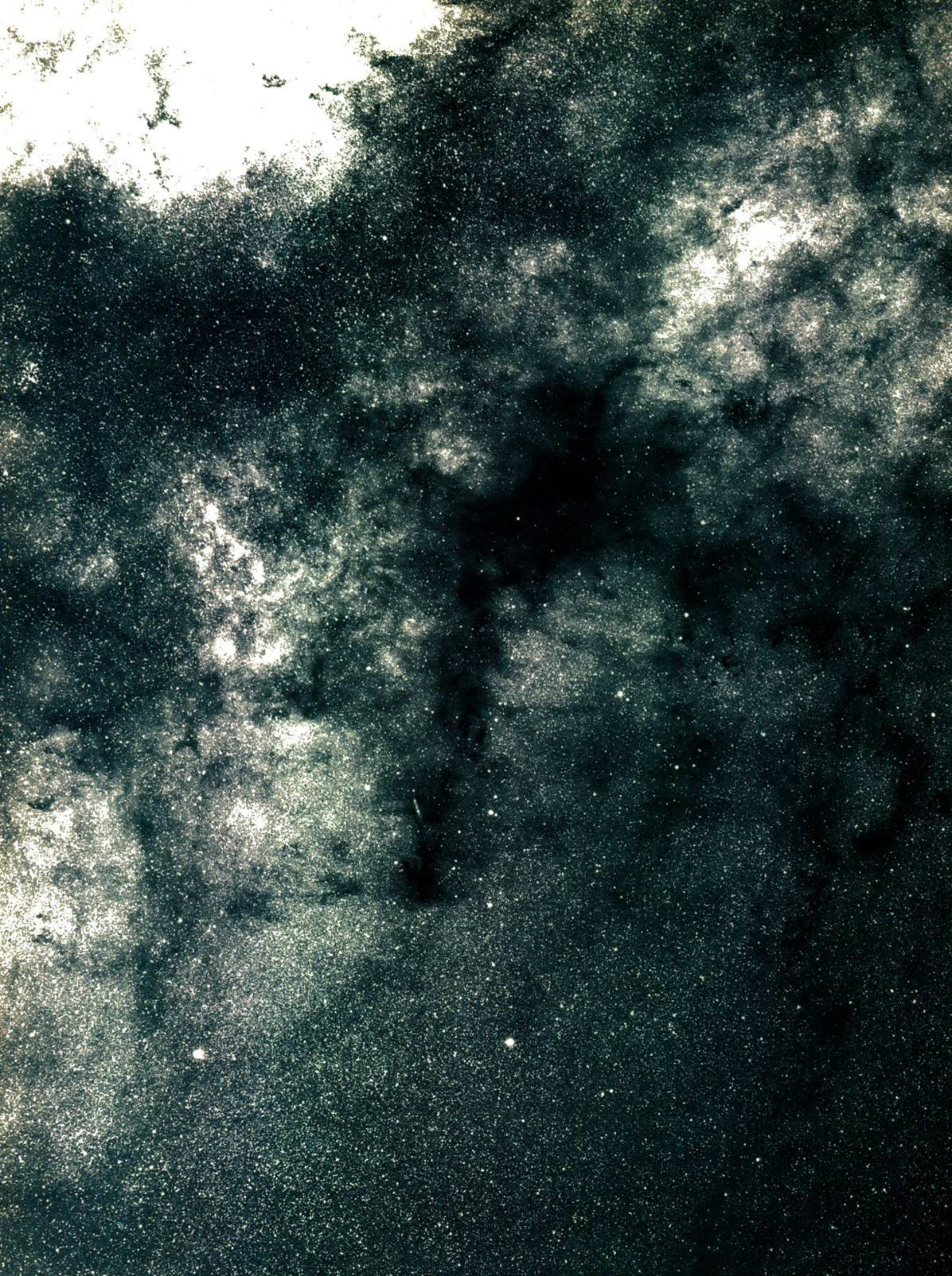
Opposite page, top: The Lagoon Nebula (M-8) in Sagittarius contains a large amount of dark nebulosity. Photo by Jack Newton.

Opposite page, bottom: A short exposure reveals many dark lanes around the hourglass-shaped nebula near M-8's center. Photo by Jack B. Marling.

In 1884 Edward Emerson Barnard, a professor of astronomy at the University of Chicago, began making long-exposure photographs of the Milky Way. For twenty-five years he photographed and studied the Galaxy and gradually came to believe its many dark lanes were pockets of obscuring material. The issue was finally settled in 1930 when Robert J. Trumpler studied the angular sizes of star clusters. Trumpler knew from previous research that the smaller the open cluster, the dimmer its stars appear. This holds true because most open clusters are relatively equal in size. However, Trumpler found that stars in many distant open clusters were much too faint to follow the formula. Thus, something was absorbing some of their light, something that lay between the cluster and us. The dimming Trumpler observed was caused by interstellar dust.

When Barnard cataloged dark nebulae, he gave them numbers, preceded by a "B" designation (for Barnard), similar to the "M" designation Charles Messier assigned nebulae and clusters in the eighteenth century. In 1927 Barnard published his catalog of 370 dark nebulae in a two-volume classic called *A Photographic Atlas of Selected Regions of the Milky Way*. The first volume contains photographic prints of regions photographed by Barnard, and the other contains descriptions of the objects and charts that correspond to the photos.

Because the photographs in this work are actual photographic prints pasted in by hand, the book was very expensive to produce, so less than a thousand copies were made. Today it is a rare item, but it can be found in university and city libraries and is sometimes offered for sale by used book dealers. Barnard's *Selected Regions* gives sizes, shapes, positions, and descriptions for his catalog of dark nebulae. The charts are easy to use because they show bright stars and NGC objects, which serve as guideposts. Although some of the nebulae visible on Barnard's photos are beyond the reach of amateur telescopes, many of these nebulae can be spotted by keen-eyed observers.



The best accessible list of dark nebulae for backyard observers appears in *Sky Catalogue 2000.0, Volume 2*. The dark nebula section lists 150 objects, giving epoch 2000 coordinate centers and brief descriptions. Opacity, or relative darkness, is also provided on a scale of 1 to 6, where 1 is the least opaque and 6 the most opaque. Two star atlases that show dark nebulae are Antonin Becvar's *Atlas of the Heavens* (now out of print but occasionally available from booksellers) and the just-released *Uranometria 2000.0*.

Dark Nebulae in the Autumn Sky

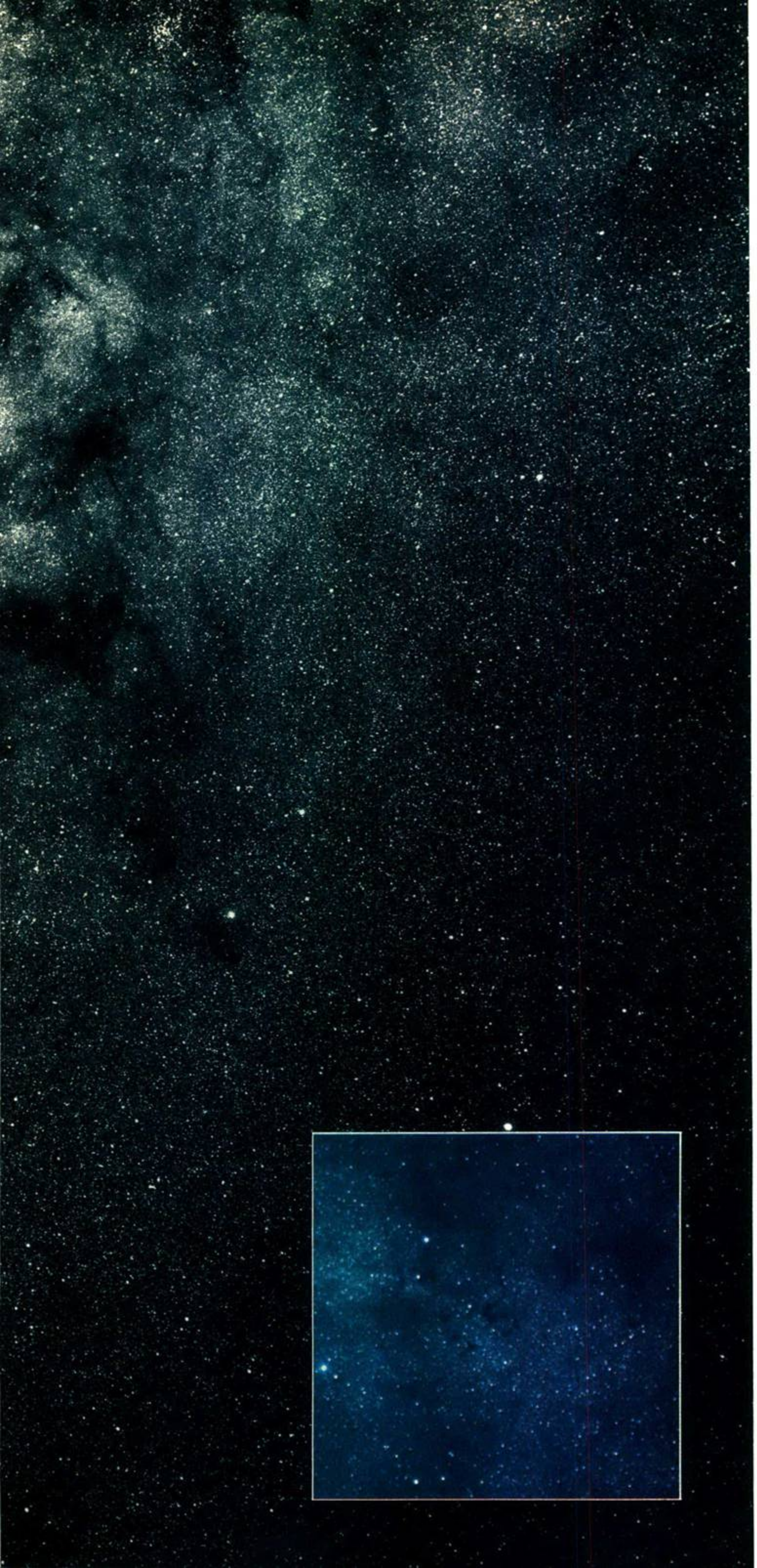
The following list of twenty-one of the best dark nebulae ranges from very easy objects to moderately difficult ones. Each dark nebula has its own distinctive characteristics. The list covers five bright early autumn constellations, all of which have bright stars that serve as guideposts for locating the nebulae.

What will a dark nebula look like in the eyepiece? It depends on the telescope, sky, and individual nebula. Some dark nebulae show well-defined boundaries; others merge gradually into the surrounding star clouds. Generally, dark nebulae appear as "blank areas" that show relatively few stars in an area otherwise packed with hundreds of stars. Some of the most dramatic examples are very opaque objects lying squarely in the plane of the Milky Way. These objects really do look like black patches or tunnels with no stars inside them. They are bordered by dense areas of stars, and the contrast is striking.

Aquila

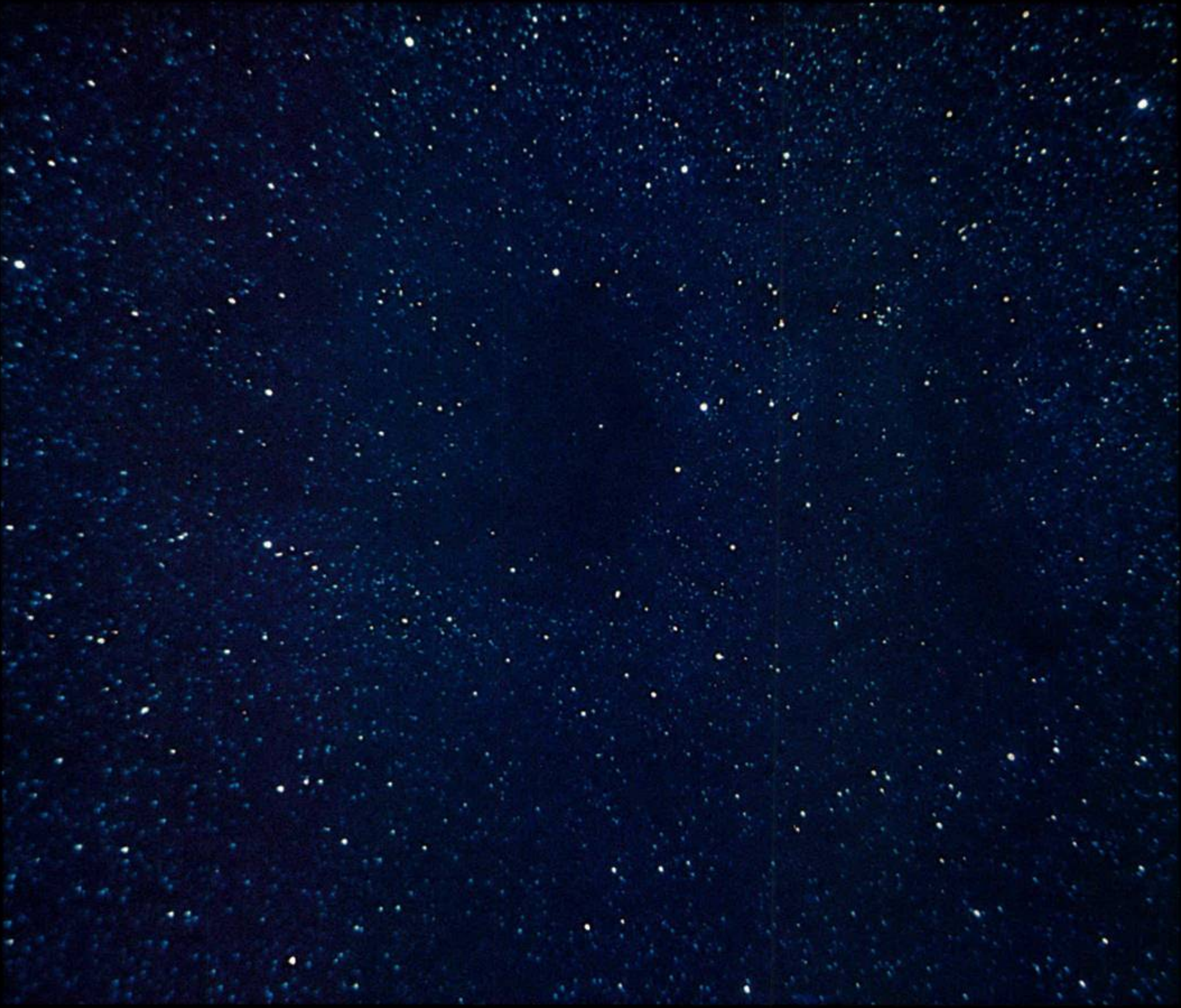
Barnard 142 and *B143*. Both of these nebulae lie about 1° west of the bright star Gamma (γ) Aquilae and only 3° northwest of Altair. B142 forms an irregular horseshoe shape. B143 has a well-defined western edge and two narrow streamers 30′ long extending to the west. The eastern edge shows no sharp outline. When observing these dark nebulae, you'll need a wide field of view.

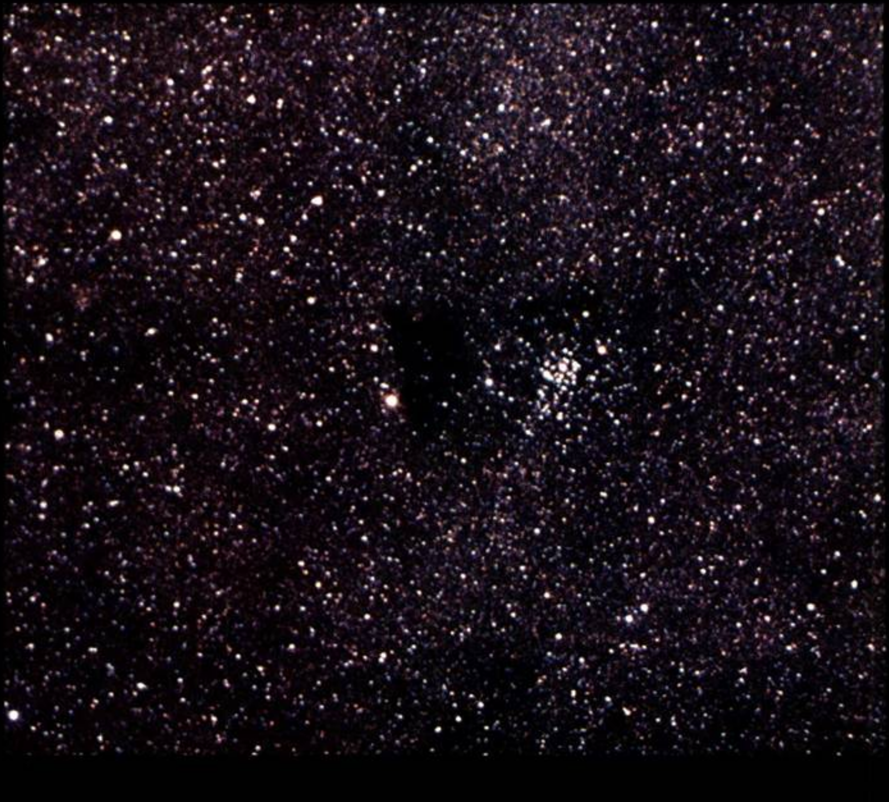
B337. This very dark nebula lies about 2° northwest of B143 and is oval in shape. It measures 3′ in diameter and contains very few stars. Although only a few stars are associated with B337, two fairly bright foreground stars lie in the middle of the nebula and help you identify the nebula.



Left: Sagittarius is a rewarding constellation for dark nebula hunters. Visible to the naked eye under a country sky, the "Great Galactic Dark Horse" is one of the Milky Way's largest and most magnificent dark structures. The Dark Horse extends through parts of Ophiuchus, Sagittarius, and Scorpius, covering thick Milky Way fields toward the galactic center. Photo by Al Lilge.

Inset: Under the Horse's belly lies the 30′-diameter dark nebula B172, also known as the "S Nebula." With a low-power telescope the S-shape is rather easy to see on a dark, moonless night. Photo by Ronald Royer.





Above: Sagittarius contains two of the sky's best and easiest to find dark nebulae. Located on the northeastern side of the bright star cloud M-24, B92 (center) can be seen with a 3-inch telescope. A solitary 12th-magnitude foreground star is the only object "within" B92. B93 (right center) is a larger, more oval nebulosity that is also easy to see with a small telescope. Photo by Scott Hicks.

Left: Four degrees south of the Lagoon Nebula lies the open cluster NGC-6520, a bright group of sixty stars bordered by dark nebulae to the north and east. The eastern nebula is B86, one of the most opaque dark nebulae in the Milky Way. This dark cloud's density and location in a rich starfield make it easy to see. Photo by Jack B. Marling.

B337 also has a narrow extension to the northwest.

Cepheus

B169, *B170*, and *B171*. All of these nebulae lie a degree northwest of Zeta Cephei. B169 is shaped like an elliptical ring about a degree wide and encloses a small group of stars. The northern portion is distinct, though the southern portion is rather ill-defined. B170 lies on the northwest edge of B169 and is an irregularly shaped strip spanning 26′ by 4′. It is very opaque, showing no stars whatsoever across its surface. B171 lies on the eastern edge of B169 and is an irregular area of nebulosity about 19′ long. This nebula is easily visible in small telescopes and shows no stars inside its boundary.

Cygnus

B145. Located about 1° northeast of 25 Cygni, B145 is a triangle-shaped nebulosity covered by a number of faint stars. It is bordered by two bright foreground stars, one on its northern edge and another on its eastern edge. The eastern edge is more opaque than the rest of the nebula. B145 measures about 45′ long and is oriented east-west.

B356. This large, oval dark nebula lies about halfway between 59 and 60 Cygni. The nebula's eastern edge is more opaque than other parts. There are some field stars scattered across its surface; a bright field star is visible on the southeastern edge.

B363. B363 is a complex of gas and dust measuring 40′ across, located just 1° northwest of the scattered open cluster M-39. The western end of B363 is larger than the eastern end, but the eastern edge has two extensions easily visible in small scopes. A bright field star lies on the southwestern edge, but few stars are visible across the nebula.

Ophiuchus

B64. This nebula lies only 30′ west of the bright globular cluster M-9. B64 measures 20′ across and is oriented north-south. This extension has an opaque northern section and a wide, less well-defined southern section.

B70 and *B74*. Both of these nebulae lie in the same wide-field eyepiece. B74 lies about 30′ west of 44 Ophiuchi, measures 15′ by 10′, and is elongated north-south. It is slightly curved and has an extension on its northern side; the western and southern sides are the most opaque. B70 lies about 30′ northwest of B74 and is much smaller, measuring 4′ across.

B72. This is one of Barnard's most famous objects, the spectacular "S Nebula." It measures 30′ across, so you'll need a wide field of view to see the "S" shape. B72 lies 30′ north of B70 and is only 2′ to 3′ wide.

Sagittarius

B85. Most backyard observers have looked at the Trifid Nebula (M-20), but few realize that the Trifid's famous dark lanes are cataloged as a dark nebula, Barnard 85. This nebula is visible in small telescopes under a dark sky and appears detailed in telescopes with 8 inches or more aperture.

B86. A fine dark nebula is located in the Sagittarius star cloud, just east of the open star cluster NGC-6520. B86 is almost square-shaped, measures about 5′ across, and has a high opacity that makes it easy to spot. With low and medium magnifications you'll see both the cluster and the nebula in the same field of view, which provides a wonderful contrast between darkness and light.

B87. Nicknamed the Parrot's Head Nebula, this large and roughly oval object lies about midway between Gamma (γ) Sagittarii and the brilliant open cluster M-7 in Scorpius. B87 measures 12′ in diameter and is surrounded by several other dark nebulae visible in small scopes. A few stars shine through the dark nebulosity.

B88 and *B89*. Both of these nebulae lie inside a well-observed Messier object, the Lagoon Nebula (M-8). With a large telescope B88 is visible along the southern portion of M-8 and has a wispy appearance. B89 is a narrow dust lane that runs almost completely across the face of M-8. It measures roughly 2′ by 0.5′ and is easily visible even in small telescopes. Next time you observe the Lagoon, try using a UHC filter: it brings out the dust lanes extraordinarily well.

B92. B92 is another dark nebula associated with a Messier object: it lies directly in front of the brightest part of star cloud M-24. The dark cloud measures 15′ by 9′ and contains a single, 12th-magnitude star in its center. B92 is one of the best-defined dark nebulae because it is surrounded by thousands of stars in the dense Sagittarius region of the Milky Way.

B93. Lying about 20′ northeast of B92 is the dark nebula B93. This well-defined object measures 6′ by 2′ across but is connected on its southern end to a dark nebulosity 15′ long. B93 is very opaque and easily seen, but the southern extension is irregularly shaped and not as easily discernible. The northern end of B93 is slightly rounded and more opaque than the southern end, which makes the northern end look like a dark comet.

B289. This large dark nebula lies 2° southwest of B93 and measures a whopping 35′ by 7′ across. It is oriented north-south and requires a wide field and north-south sweeping to spot.

Dark nebulae provide a wonderful escape from the tried-and-true showpiece objects like the Orion Nebula and the Andromeda Galaxy. The next time you are out under a dark sky, take on the challenge of seeing some patches of dark cosmic dust.

Summer Dark Nebulae

Object	R.A. (2000)	Dec.	Con.	Opacity	Size
B244	17h10.1m	−28°24′	Oph	5	30′ x 20′
B250	17h13.1m	−28°21′	Oph	5	15′
B64	17h17.2m	−18°32′	Oph	5	20′
B70	17h23.5m	−23°58′	Oph	4	4′
B72	17h23.5m	−23°38′	Oph	6	30′ x 3′
B74	17h25.2m	−24°12′	Oph	5	15′ x 10′
B289	17h56.6m	−29°01′	Sgr	5	7′ x 35′
B85	18h02.6m	−23°02′	Sgr	6	—
B86	18h02.7m	−27°50′	Sgr	6	4′
B88	18h03.8m	−24°23′	Sgr	5	2.7′ x 0.5′
B89	18h03.8m	−24°23′	Sgr	6	2′ x 0.5′
B87	18h14.3m	−32°30′	Sgr	5	12′
B92	18h15.5m	−18°11′	Sgr	6	12′ x 6′
B93	18h16.9m	−18°04′	Sgr	5	12′ x 2′
B337	19h36.8m	+12°27′	Aql	4	3′
B340	19h49.1m	+01°25′	Aql	5	7′
B142	19h40.7m	+10°57′	Aql	6	40′
B143	19h40.7m	+10°57′	Aql	6	30′
B145	20h03.5m	+86°02′	Cyg	4	35′ x 6′
B356	21h01.9m	+06°31′	Cyg	4	24′
B363	21h26.6m	+08°36′	Cyg	5	40′ x 7′
B169	21h58.9m	+58°45′	Cep	5	60′
B170	21h58.9m	+58°45′	Cep	5	26′ x 4′
B171	21h58.9m	+58°45′	Cep	5	19′

David Higgins frequently observes dark nebulae with his 24-inch telescope in Krebs, Oklahoma. For the past two years he has helped operate the Texas Star Party and is one of the creators of the Okie-Tex Star Party. Higgins is a contributing editor of Deep Sky and central coordinator of the National Deep Sky Observers Society.

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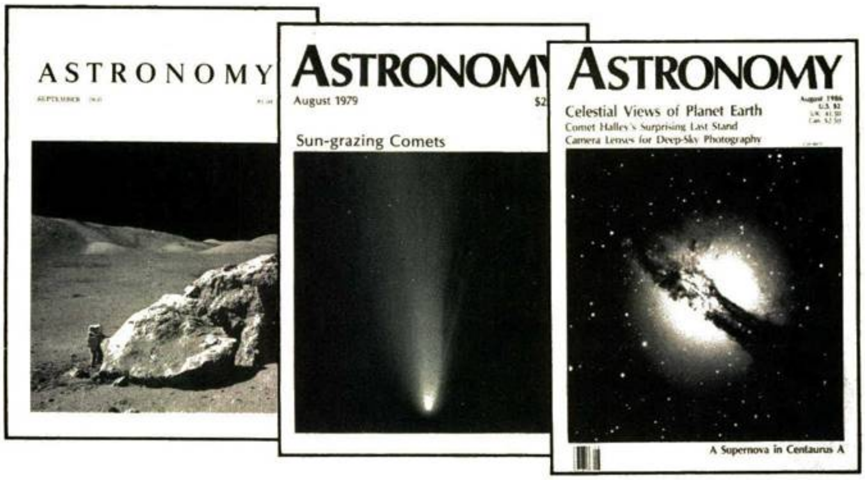
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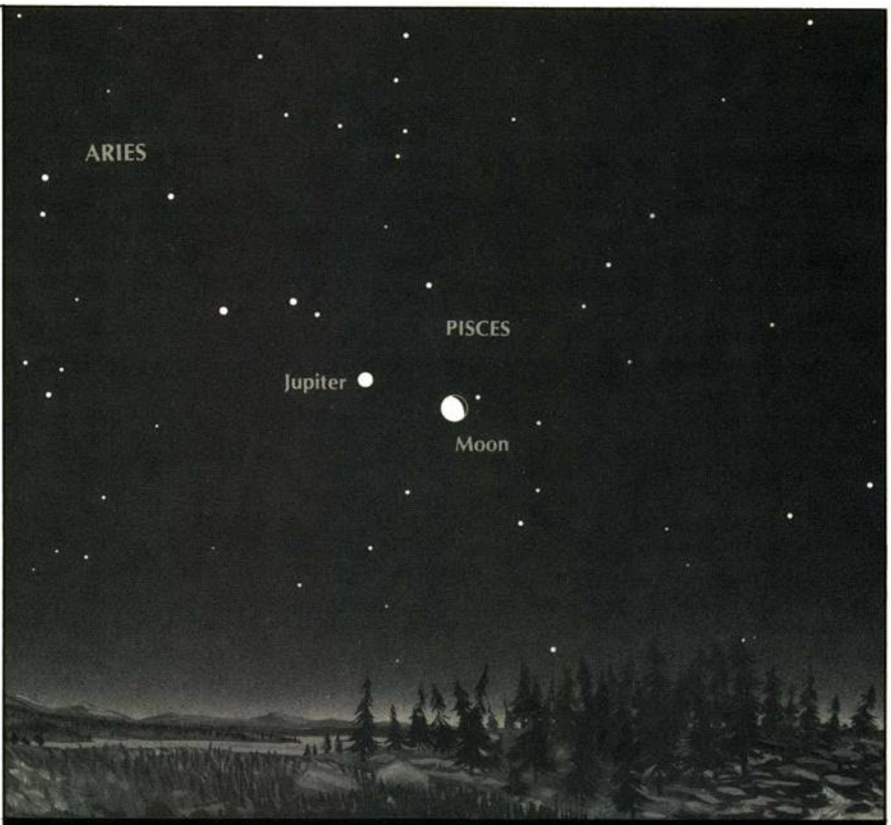
Seeing the Zodiacal Light

by Robert Burnham



Looking east, September 10, late evening

The Wanderers

The early evening skies this month show only two planets, one of them very hard to see. **Saturn** is the easy object, shining at magnitude 0.5. As twilight fades, Saturn is the "star" about one hand's span above the south-southwestern horizon. It shines with an ivory color. If the view below the planet is unobstructed, you'll see the star Antares lying to Saturn's lower right. Compare Antares' orange-red color and its brightness with those of Saturn.

Late in September **Mercury** creeps into view in the southwest. It lies extremely low, however. At best visibility it will be only two Moon-diameters above the horizon, forty-five minutes after sunset. Unless you have a flat horizon, no clouds, and a bit of luck, you will probably miss Mercury. (Binoculars will certainly help you find it.) On September 22, −0.1-magnitude Mercury lies about one Moon-diameter away from 1st-magnitude Spica, though seeing them in the bright twilight will be a challenge.

In the later evening hours this month a brilliant white planet will rise in the east: **Jupiter** at magnitude −2.8. By the time Saturn sets, Jupiter will be the prominent "star" in the east. If you view with binoculars over a week or two, you'll notice Jupiter is drawing near a 4th-magnitude star, Omicron (ο) Piscium. Jupiter passes due north of the star on September 25, though the planet will lie near the star for several days. Can you see the star with your naked eye when Jupiter is closest? When do you lose sight of it in Jupiter's glare?

Last month two planets vanished into conjunction with the Sun. **Venus** remains invisible, but during the last week of September **Mars** appears very low in the east about half an hour before sunrise. It is shining at magnitude 1.8 but seems dimmer because of the bright twilight sky around it. (If you can't find it now, try again in mid-October.)

Autumn is one of two seasons offering good chances to see the elusive **zodiacal light**. Often mistaken for dawn, the zodiacal light is a soft glow that rises up from the eastern horizon before morning twilight in fall. In the spring it extends upward from the western horizon after evening twilight. It has the shape of a tall skinny triangle, widest and brightest at the horizon and tilted to follow the ecliptic, along which the constellations of the zodiac are situated (hence the name zodiacal light). At its greatest extent the zodiacal light can be traced across about a third of the sky. It is caused by sunlight scattering off trillions of dust particles that orbit the Sun in the plane of the solar system.

To see it best, go far away from city lights and find a site with a clear view of the eastern horizon. Arrive about two hours before sunrise on a night with no Moon. When your eyes have dark-adapted, look for the zodiacal light between Pollux in Gemini and Procyon in Canis Minor. If the sky is completely clear and dark, the wedge of light will reach up to the Pleiades or farther.

The Starry Sky

This month the **Milky Way** spans the sky from southwest to northeast, separating the setting spring constellations from the rising star-figures of autumn. Low in the southwest where the Milky Way is brightest, the Archer **Sagittarius** forms a teapot or kettle tipped westward. (Think of the Milky Way as steam from Sagittarius' spout.) The Archer's brightest star, Sigma (σ), is named Nunki. This star and its neighbors on the eastern side of the Teapot form a small asterism called the "Milk Dipper." Can you see it?

The region between Sagittarius and **Scutum** the Shield is rich with stars and nebulae and well repays slow sweeps with binoculars. Above this region **Aquila** the Eagle forms a large diamond with a line running down to Scutum. Everyone agrees the diamond marks the Eagle's outstretched wings, but some writers call

Opposite page: In September and October you have an excellent opportunity to look for the softly radiant zodiacal light in the morning sky an hour or two before dawn. If your skies are dark and very clear, you might see the pyramid-shaped glow extending well past the zenith. The brightest portion can be brighter than the Milky Way in Sagittarius. Gregg Thompson made this 14-minute exposure with a 17mm lens at f/3.5 on hypered Fuji 400 film from Siding Spring Observatory in Australia. The angular extent of the glow in this photo — from top to bottom — is about 110 degrees.

For information on viewing the Moon, planets, and deep-sky objects with telescopes, see **The Backyard Astronomer**.

September Night Sky

Full Moon
September 7
2:13 p.m. EDT

Last Quarter
September 14
7:44 p.m. EDT

New Moon
September 22
11:08 p.m. EDT

First Quarter
September 30
6:39 a.m. EDT

1st The Moon lies south of Antares and Saturn this evening. (Antares was occulted earlier in the day for viewers in Indonesia and Australasia.) During the coming week (until Full Moon) look for the zodiacal light in the east before morning twilight begins (see text).

5th The Moon is closest to Earth at 11:43 p.m. EDT: 224,269 miles (360,926 kilometers).

7th Full Moon occurs at 2:13 p.m. EDT.

10th Tonight the Moon glides past Jupiter in the late evening sky (see diagram on page 54).

14th Last Quarter Moon is at 7:44 p.m. EDT.

17th The Moon is farthest from Earth at 11:05 p.m. EDT: 251,772 miles (405,189 kilometers).

22nd New Moon is at 11:08 p.m. EDT; an annular eclipse of the Sun is visible in Asia and the western Pacific Ocean. Mercury lies about half a degree away from Spica (in Virgo) in the evening sky but will be barely visible in the twilight (see text).

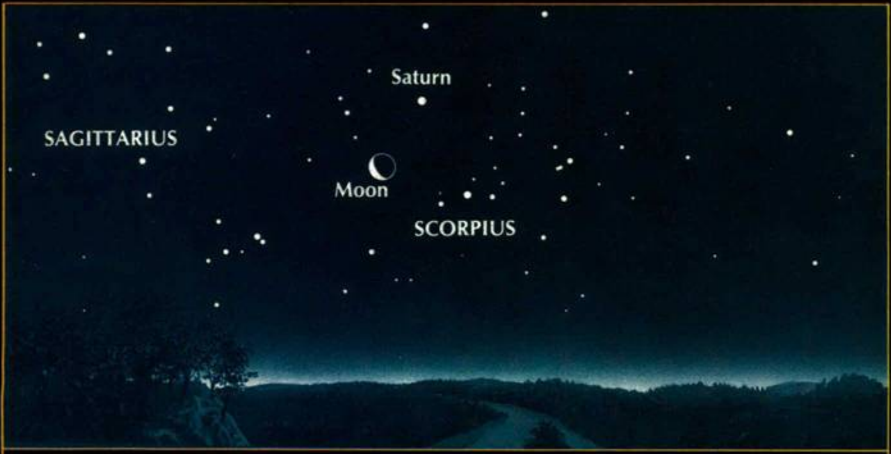
23rd The Sun crosses the celestial equator, moving southward, at 9:45 a.m. EDT. This is the autumnal equinox, which marks the beginning of fall in the Northern Hemisphere.

25th The Moon occults Spica and Mercury for viewers in Japan and the northwestern and southern Pacific Ocean (Spica) and India, Malaysia, Indonesia, and Australasia (Mercury).

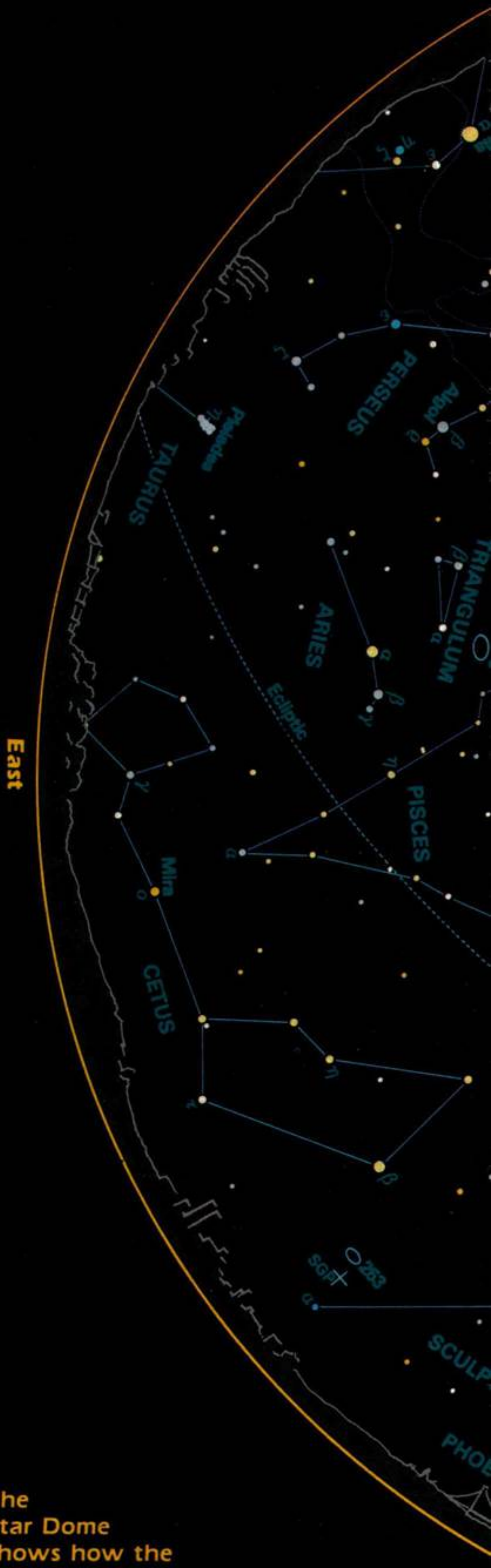
28th For the second time this month the Moon passes south of Antares and Saturn in the evening sky (see diagram below). Antares is occulted for viewers in southern Africa, Madagascar, the Indian Ocean, and Australia.

29th Mercury is at peak elevation for this apparition, but it is very low and hard to see in the southwestern evening sky.

30th First Quarter Moon occurs at 6:39 a.m. EDT.

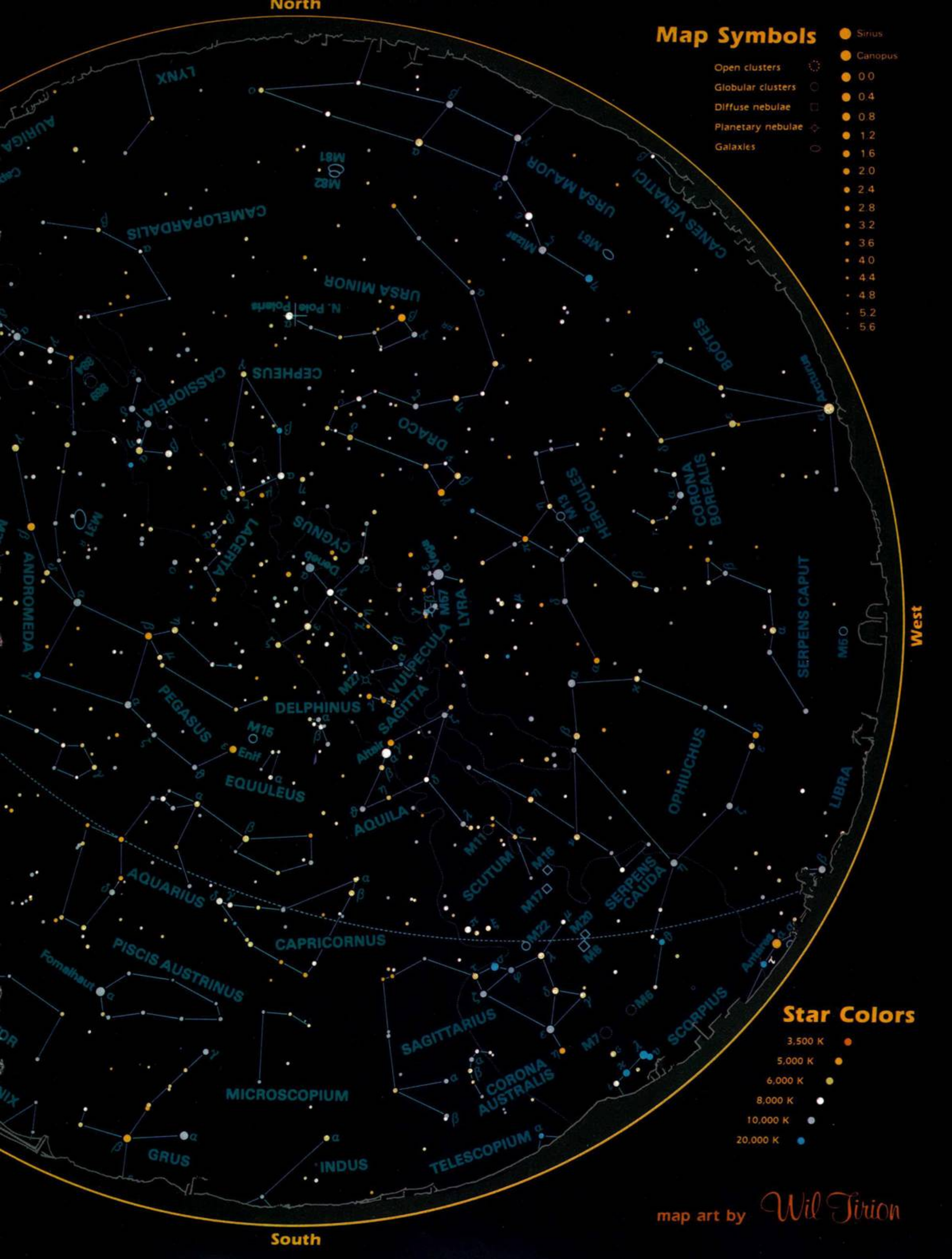


Looking southwest, September 28, one hour after sunset



The
Star Dome
shows how the
sky looks at:

11:30 p.m. on September 1
10:30 p.m. on September 15
9:30 p.m. on September 30


North
South
West
Map Symbols
Open clusters
Globular clusters
Diffuse nebulae
Planetary nebulae
Galaxies
Sirius
Canopus
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
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5.2
5.6
Star Colors
3,500 K
5,000 K
6,000 K
8,000 K
10,000 K
20,000 K
LYNX
AURIGA
URSA MAJOR
CANES VENATICI
M81
M82
CAMELOPARDALIS
Mizar
M51
URSA MINOR
N. Pole
Polaris
BOÖTES
Arcturus
CEPHEUS
CASSIOPEIA
884
869
DRACO
CORONA BOREALIS
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M13
M31
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Antares
PISCIS AUSTRINUS
Fomalhaut
M6
SCORPIUS
SAGITTARIUS
M7
CORONA AUSTRALIS
MICROSCOPIUM
GRUS
INDUS
TELESCOPIUM

map art by Wil Tirion

1st-magnitude Altair the Eagle's head, others its tail. Because most people nowadays see Altair as the Eagle's tail, we'll imagine the Eagle is heading south for the winter.

Cygnus the Swan is another migrant bird pointed south. The star Beta (β) is named Albireo and marks the Swan's head, bright Deneb is its tail, and two wings spread out from Gamma (γ) in the center. Below Deneb as you face west is another 1st-magnitude star: Vega in diminutive **Lyra** the Lyre. Together Vega, Deneb, and Altair form "the Summer Triangle," a large asterism seen in summer and early autumn.

Overhead in Cygnus the bright portion of the Milky Way comes to an end. Down to the northeast horizon the Milky Way fades appreciably, though **Cepheus** the King and **Cassiopeia** the Queen stand out clearly. Poised over the pole star, Cepheus looks like a distorted home plate or perhaps an old-fashioned fountain pen nib. To the right of Cepheus, Cassiopeia's bent "W" depicts an uncomfortable-looking throne, now upside down. Below Cassiopeia **Perseus** the Rescuer is rising.

The two Bears (**Ursa Major** and **Ursa Minor**) and the great Dragon **Draco** circle around the pole (see Skylore). Though the Big Dipper is the best-known part of Ursa Major, the Big Dipper actually forms only about half of the constellation; the rest of the stars are 3rd magnitude or fainter and hard to see from urban locations.

The autumn sky always seems like a dark wasteland after the summer Milky Way's stellar riot. But most of us who live near light-polluted cities never see this region as it should be seen, because only under dark country skies do its constellations come into view. In the southeast a bright star stands alone. Named Fomalhaut, Arabic for "the mouth of the fish," it lies at the eastern end of **Piscis Austrinus** the Southern Fish. The rest of the Southern Fish extends pennantlike to the west. **Capricornus** the Sea Goat is a member of the zodiac and resembles a wide triangle with pairs of stars at its northeast and northwest tips. Above Fomalhaut, the Water Carrier **Aquarius** pours a stream of water from a jug he holds into the Southern Fish's mouth. (You'll need dark skies and some imagination!)

High in the southeast is a square poised on one corner, the Great Square of **Pegasus** the Flying Horse. The horse is inverted with the Square marking its wings and the star Enif its nose. The Horse's forelegs reach toward Cygnus. As you face east, the Fishes of **Pisces** embrace the lower half of the Great Square. (Jupiter lies in the midst of Pisces, dimming the constellation's stars.) Look for the western Fish as a circlet of 4th-magnitude stars between the Great Square and Aquarius.

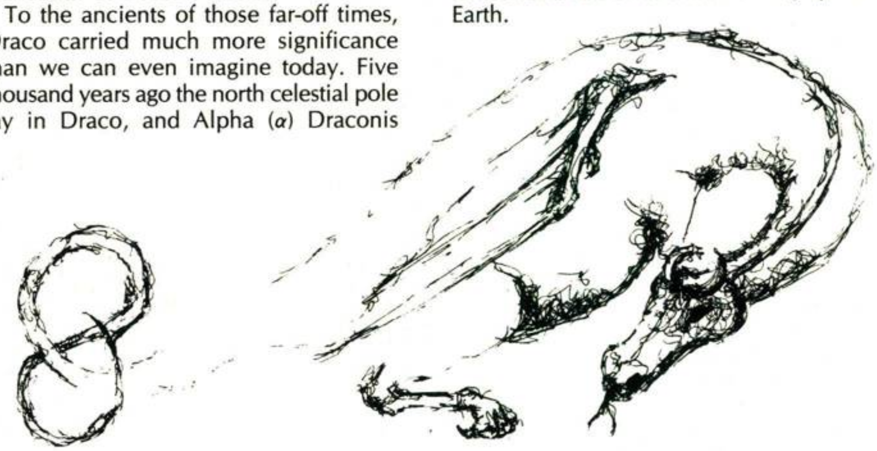
Did you notice that the Great Square has two Alpha (α) stars? The left-hand Alpha (as you face east) actually belongs to **Andromeda** the Princess and is called Alpheratz. Andromeda was the daughter of Cepheus and Cassiopeia. She was rescued by Perseus when she was threatened by **Cetus** the Whale, now on the eastern horizon. Andromeda comprises two curved lines spreading northeast from Alpheratz. On a dark night try to locate the Great Galaxy (shown as M-31 on the map). Under good skies it is visible to the naked eye and viewed easily with binoculars.

Opposite page: The Moon and Venus set into a deep red sky over Honolulu on January 15, 1983. William Sager used high-speed Ektachrome film, a 135mm lens at f/2.8, and a 5-second exposure to capture the scene.

Skylore

Wrapped around the pole and dividing the Large and Small Bears is the great sinuous monster Draco. While dragons don't inhabit our nightmares much any more, dragons certainly terrorized many early cultures. Our Draco comes from the Middle East, circa 3000 B.C., where it was known as Tiamat, the ruler of the salt waters and bringer of chaos. Tiamat was defeated in a titanic battle by the hero Marduk, who then created heaven and Earth from the torn fragments of Tiamat's body (see Skylore, April 1987). Marduk was commemorated in the stars along with Tiamat and is known to us as Hercules, the figure who kneels upside down just south of Draco's head.

To the ancients of those far-off times, Draco carried much more significance than we can even imagine today. Five thousand years ago the north celestial pole lay in Draco, and Alpha (α) Draconis (named Thuban) was the pole star. Every night the ancient Mesopotamians watched the star-figure that represented the forces of chaos slowly pinwheel around the world with its unblinking, hate-filled eyes turned on the events below, threatening to return and destroy mankind.



Thousands of years later the early Greeks devised two myths involving Draco. The first is probably older because it deals with a fight between the immortal gods and a long-vanished race of superhumans known as the Gigantes, or Giants. They were large, fierce men with terrible faces, serpent legs, and bitter hostility toward the deities on Mount Olympus.

Angered because Zeus had locked up their brothers, the Titans, in Tartarus, the Giants attacked the Olympians, flinging boulders and flaming trees up at the Olympians' home in the sky. The gods were nearly overwhelmed; it wasn't until the prophesied "man in a lion skin" (Hercules) stepped in that the tide of battle turned in the gods' favor. Even so, Hercules would have been helpless had he not been armored with an herb that conferred invulnerability. At the crux of the fight Athene grabbed one of the Giants — a particularly foul-breathed individual — and flung him into the northern sky where, as Draco, he writhes ceaselessly.

The second myth has an element of farce. Hera gave Zeus three golden apples as a wedding present. For safekeeping they were placed in the Garden of Hesperides, the paradise at the end of the world under the guard of a dragon. In this garden also was Atlas, the god who carried the globe on his shoulders and the only creature the dragon allowed to approach unharmed.

As one of his twelve labors to earn immortality, Hercules was compelled to steal the apples. In the Garden he asked for help from Atlas, depicted in the myth as a big, dumb, friendly fellow. The deal they struck was that Hercules would take over holding up the world while Atlas stole the apples for him. The snag came when Atlas, once freed of his awful burden, decided to keep the apples for himself and leave Hercules holding up the Earth.

But Hercules was pretty smart. He told Atlas he didn't mind carrying the world, but first he would need to get a shoulder pad to rest it on. Atlas fell into the trap and took back the burden. Hercules then picked up the golden apples, laughed wickedly, and walked off.

In the end Hera was enraged because the dragon had failed in its duty to guard the golden apples, so she seized the ill-fated creature and placed it among the chilly circumpolar constellations. Because it never sets, Draco was henceforth compelled always to be on guard.

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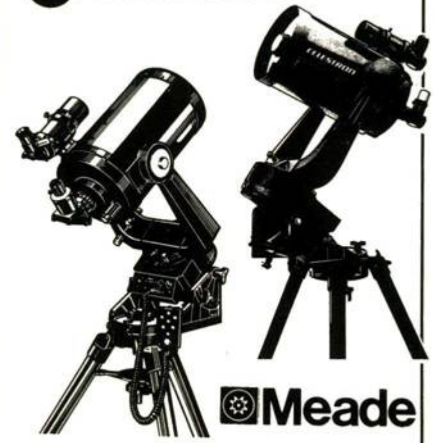

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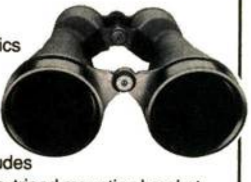

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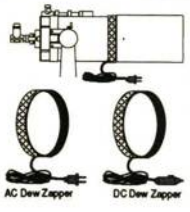

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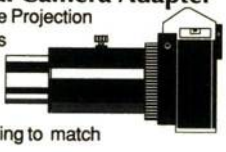

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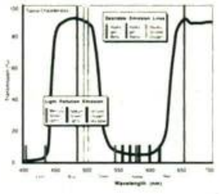

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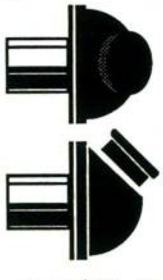

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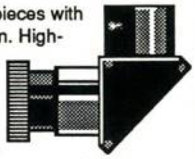

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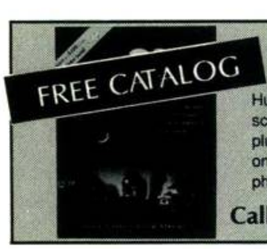

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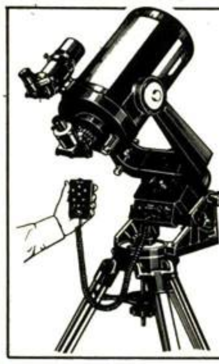

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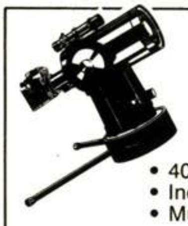

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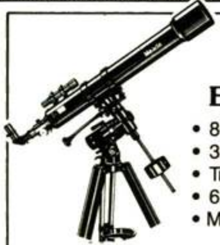

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Simulating Clusters on Your Computer

Equipment Atlas

by Thomas B. Woods

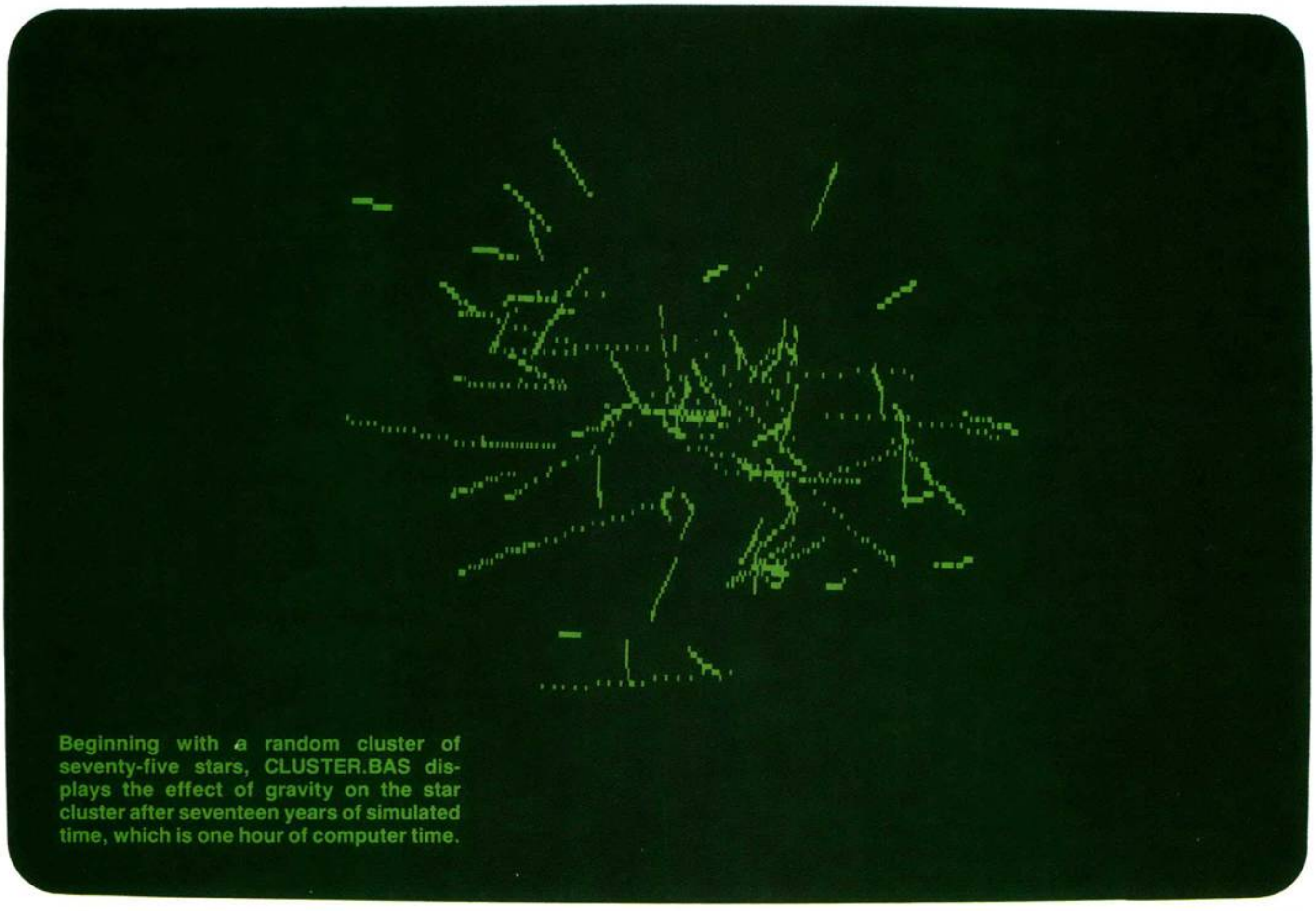
As twilight fades into darkness an ominous cloud bank rolls in from the west, and another night of observing goes down the tubes. Dejected, you decide to spend the evening running some new programs on your personal computer. You sit down at the keyboard, press a few keys, and soon stars are tracing intricate patterns across the computer screen.

The cosmic ballet you have just seen is the output of a computer program called CLUSTER.BAS. With this program you can create your own cluster of stars and then watch as the computer calculates and displays the effect gravity has on stellar motions as the cluster evolves.

CLUSTER.BAS is a simulation: it mimics reality on your computer screen. Scientists use simulations to study phenomena that are too dangerous or too inaccessible to observe firsthand as well as processes that take generations to occur in real time. A computer, programmed with the physical rules that govern an event, can compress a millennium into just a few minutes or reduce a hazardous environment to a pretty display or a useful stream of numbers.

Despite the relatively high velocities of the stars in a cluster, these stars are so far away that little, if any, motion is visible from Earth (although radial velocities testify to the movement of these stars). For this reason astronomers use computers to simulate the behavior of star clusters, seeking to understand the dynamics of these stellar groups by compressing years of motion into a few seconds of computer time. CLUSTER.BAS gives you the same opportunity to view a dynamic system in a reasonable span of time.

The program displays a cluster as you would see it through an incredibly powerful telescope. A tiny portion of the sky is magnified to fill the computer screen,



Beginning with a random cluster of seventy-five stars, CLUSTER.BAS displays the effect of gravity on the star cluster after seventeen years of simulated time, which is one hour of computer time.

and your "telescope" can separate stars just a few astronomical units (AU) apart.

You decide how the cluster starts out: as a tightly packed group of one hundred stars; a loose grouping of twenty stars; a binary, triple, or quadruple star system; or anything in-between. The program then plots the positions of the stars on your monitor and traces the paths the stars make as they move under the influence of gravity. Depending on the initial cluster, the star trails may go straight off the screen, or complex spirals and loops may form.

Running the Program

I wrote CLUSTER.BAS on an MS-DOS (version 2.11) computer in GW-BASIC, the programming language common to most PC compatibles. To run the program, you need a computer with a Color Graphics Adaptor (CGA) card, which allows your computer to plot pixels on the screen.

To enter the program into your machine, load your BASIC language and then key in the listing shown here. When you're finished, save the program onto disk by entering the command SAVE "CLUSTER".

To start the program, type RUN. A menu will appear, giving you several options for loading, saving, and plotting clusters. Type the number of the option you want to use and press ENTER to execute the option.

The first thing you must do is create a set of stars for the computer to plot. This can be done several ways. Option one allows you to enter a collection of stars by hand. The computer will ask you to input the initial X, Y, and Z spatial coordinates for each star (distances are measured in AU). The origin of the coordinate system, where X, Y, and Z all equal zero, is at the center of the screen. Positions can take on either positive or negative values: positive values place a star right, above, and behind screen center, respectively, for the X, Y, and Z coordinates, and negative spatial coordinates correspond to left, below, and in front.

Next the computer will ask for the mass of each star (in solar masses) and finally for the initial X, Y, and Z velocities. Velocity works the same way position does: each star has an X, Y, and Z velocity vector. The values you assign to each are interpreted in AU per year.

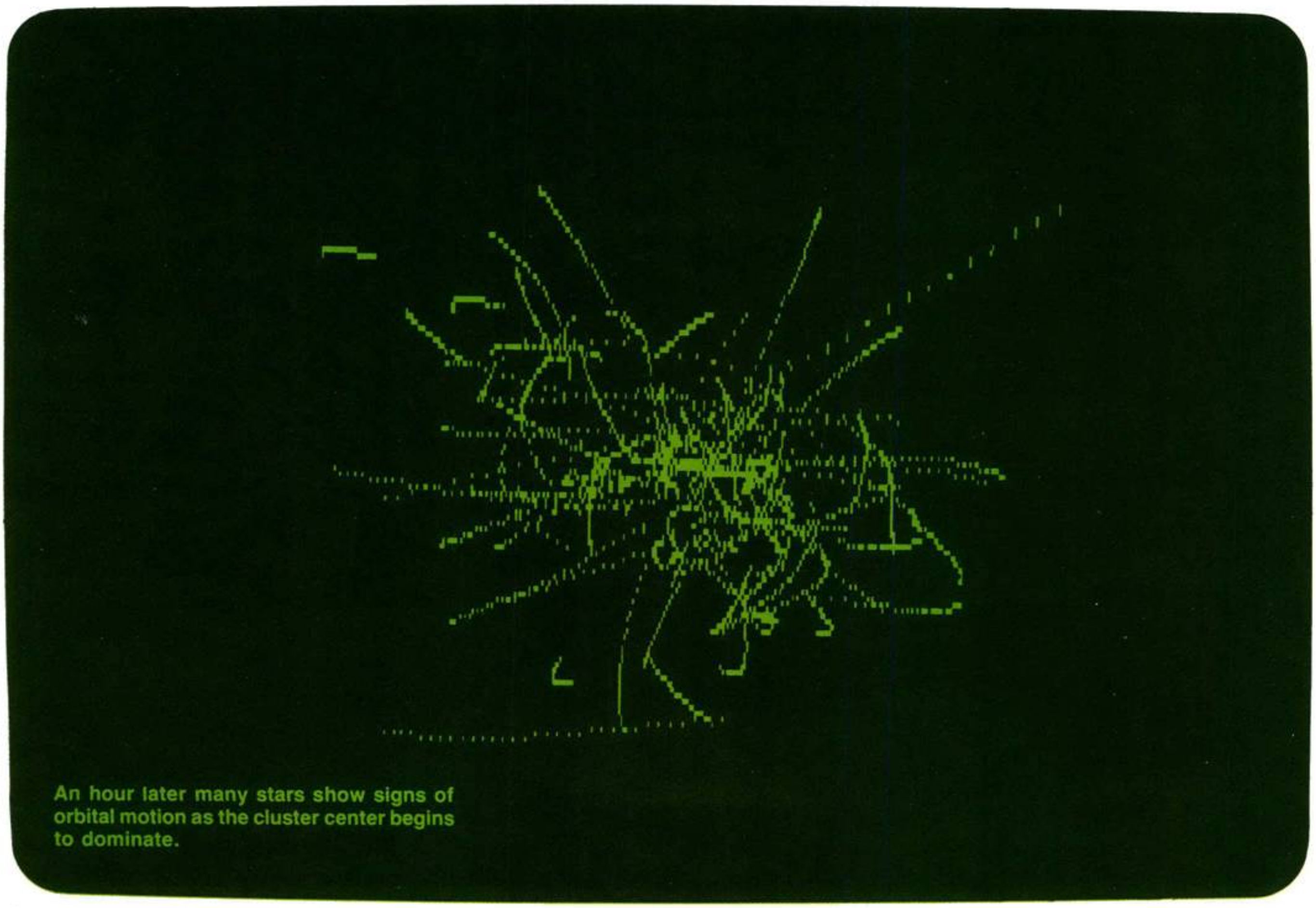
A simpler way to create a set of stars is by having the computer generate a random cluster. Menu option two creates this cluster for you. The computer asks how many stars you want in the cluster and how tightly packed you want them. The number you enter as the "density factor" is the percentage of the screen area that will be filled. A low value entered here produces stars packed tightly around the center of the screen, while a higher input spreads the stars out. The computer then uses a RND function to position the stars according to the density factor. The computer also generates stellar masses and velocities. Masses will be up to 4 solar masses, while velocities will be between −1 and +1 AU per year (approximately −5 to +5 kilometers per second).

Option three lets you load a set of stars that were previously saved on disk with option four. Use option four to save the initial star parameters, and then if you like the results of the plot you can call them back later with option three.

You can also enter star data by combining the first three options. For instance, you could generate a random set with a density of seventy-five and then add another random set with a density of twenty to produce a "layered" cluster. To this set you could load a set of stars from disk with option three, or even add a few stars by hand with option one.

Option four lets you save a set of star positions on disk. When you select this option, the computer displays a list of all the star sets currently on the disk you're using so you don't write over data you have previously saved. You're then asked for a filename to save your current stars under. These stars are stored in files with the ".PTS" filename extension, so be sure to add this extension to the name you assign. With this feature you can run a plot, load the original set back into your computer with option three, and then add another star with option one to see how it affects the cluster's motion.

CLUSTER.BAS uses files of two types: those with the ".PTS" extension and those



An hour later many stars show signs of orbital motion as the cluster center begins to dominate.

with a ".PLO" filename extension. ".PLO" files are PLOT files used in conjunction with options five and six. These files are records of the movements of a group of stars. You can load the record into the computer with option five and save the record with option six, which is analogous to the operation of options three and four. As with ".PTS" files, you will be asked to enter a filename — be sure to add the ".PLO" extension.

Options five and six are useful because running a large cluster plot can take several hours. If the plotting sequence is recorded on disk, it can be loaded back into the computer quickly because the program doesn't need to perform any calculations. Once a PLOT file has been opened, running a subsequent star plot will write the stars both to the screen and to the disk. When a PLOT file is closed, stellar motions are written only to the monitor.

The next menu selection, option seven, displays the numeric values of the position, velocity, and mass for each star. This display is handy when you set up the initial star points and want to check them. You can also use this option to compare values before and after a cluster is plotted and see the quantitative changes produced by the program.

Option eight is the workhorse of CLUSTER.BAS — it sets the stars in motion. Once you enter this display mode, each star is shown at its entered position. As gravity acts, the star positions change, and trails are left so you can see the cumulative effects.

Once you begin a plot, the computer will continue in this mode until you press a key on the keyboard. Then the "elapsed time" in years is shown at the top of the screen, and the program holds the display until you press another key. At this point press ENTER to resume plotting stars or press any other key to go back to the main CLUSTER.BAS menu.

Option nine clears a star cluster from memory in preparation for creating a new one. This option *must* be selected every time you want to create a new star cluster. If you do not erase the old stars, all of the star-making functions (input, random, and load) will add more stars to those you have already collected. This is a nice feature if you want to experiment with gravity by building up a complex array of stars, but it means you must intentionally erase a cluster before a new one can be created.

The last option, option ten, permits you to change the field of view. The program's initial setting shows an area of 400 by 300 AU. If you want to change to a broader view, choose option ten and select a view of 800 by 600; 1,333 by 1,000; or 6,666 by 5,000 AU. Option ten also gives you three narrower field sizes of 133 by 100; 40 by 30; and 13 by 10 AU. These fields are particularly useful if you want to experiment on a solar system scale, such as simulating the orbit of Jupiter.

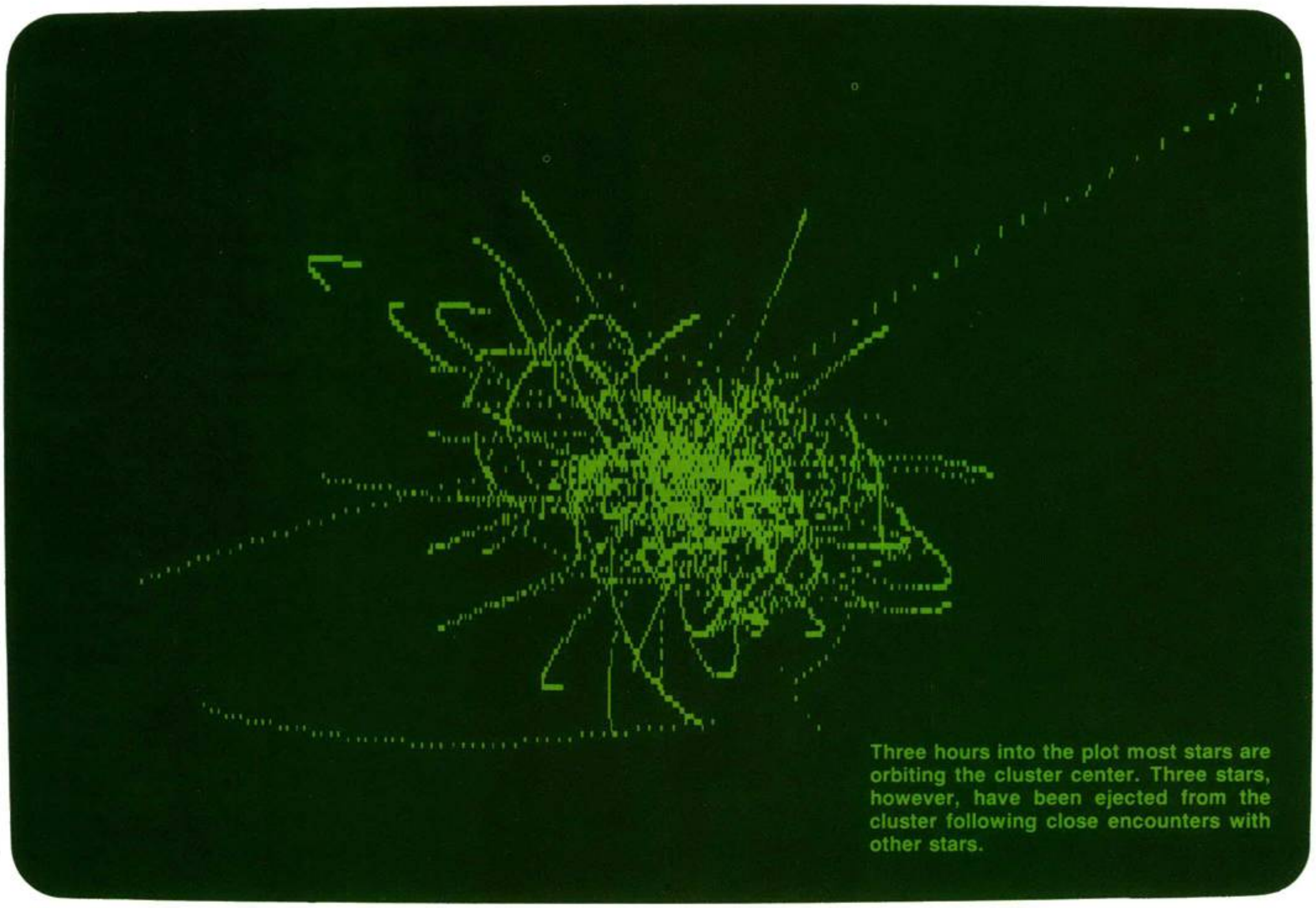
Creating a Cluster

Because the law of gravity is universal, the motion of one star in a cluster is affected by the gravitational attraction of every other star. To arrive at the total gravitational attraction, the computer must add together all the individual effects.

First the distance separating the two stars is determined. From this the force of gravity is calculated using Newton's relationship: Force equals the product of the two masses divided by the square of the distance between them. This force produces an acceleration — a change in velocity — and from that the new velocities can be found. Updating the positions of the stars is a matter of adding the new velocity vector to the old position coordinate. The cluster occupies three physical dimensions, so forces, accelerations, velocities, and positions must be calculated for each X, Y, and Z dimension.

This means CLUSTER.BAS spends a lot of time calculating. The length of time it takes to plot a new point depends largely on the number of stars you have in your cluster. Four or five random stars with a density factor of about fifty produce aesthetically pleasing stellar motions within several minutes. At this density, gravity has a powerful effect, and stars dance across the screen shortly after a plot starts.

The program can handle plots of up to one hundred stars, but then you must be prepared to wait several hours to see your pictures "develop." The time needed to



Three hours into the plot most stars are orbiting the cluster center. Three stars, however, have been ejected from the cluster following close encounters with other stars.

calculate and plot a group of stars depends on the square of the number of stars, so doubling the number of stars takes four times longer to plot. What you see in one minute on a plot with five stars will take about six and a half hours with one hundred stars.

If you want to run a long plot, start it and then do something else. A slow plot is tiresome if you're staring at the screen waiting for something to happen. Take heart, only a decade ago a similar plot done with a calculator and graph paper would have taken months or even years to complete.

Writing this program, I took a few liberties with celestial mechanics to speed up the calculations. Although CLUSTER.BAS does a fine job of showing the power of gravity, these liberties mean the program is not perfectly accurate.

For instance, as in any digital computer, time cannot be treated continuously — the computer instead increments time in discrete units. Regardless of how small these units are, subtle effects that will lessen the accuracy of the results may occur in the interim. Another major drawback is the serial nature of the calculations. In reality every star is continually influencing every other star, but in CLUSTER.BAS the gravitational force on each star is calculated separately. This means, for example, that in a three-star plot the third star is influenced by the other two stars after they have moved to their new, updated positions.

In addition, problems with pixel size, the accuracy of floating point numbers, computer speed, and my lack of knowledge have contributed small errors. Nevertheless, the program is accurate enough to give you an enlightening demonstration.

After running CLUSTER.BAS a few times, you may be surprised to see that star motion can produce a totally different cluster after just a century or two. This is definitely not the way things work in the real sky. Why is CLUSTER.BAS different? The apparent speed of stellar motions can be attributed to the proximity of the stars you are watching. Remember, your computer screen shows stars separated by astronomical units, not light-years. Because gravitational force varies inversely with the square of the distance, close stars have a profoundly greater influence over one another than stars spaced several light-years apart. Movement in CLUSTER.BAS reflects this, so motion is great.

Star Collisions

Collisions and near misses between stars pose special problems for CLUSTER.BAS. When stars pass so closely that they graze or collide, the computer has a hard time calculating the true velocity and position of each star. The "slingshot" effect caused by a near miss is mistakenly magnified, and a cluster suffering from these occurrences tends to dissipate

CLUSTER.BAS

```
1 REM ***************** CLUSTER.BAS *****************
2 REM ***                                         ***
3 REM *** This program simulates the motion of a  ***
4 REM *** cluster under the influence of gravity. ***
5 REM ***                                         ***
6 REM ***********************************************
7 DIM FLD(7):FLD(1)=10:FLD(2)=30:FLD(3)=100:FLD(4)=300
8 FLD(5)=600:FLD(6)=1000:FLD(7)=5000
10 SCREEN 2:DEFINT I,J,Y:KEY OFF:X=0:WFLG=0
12 DIM ACC(100,3),V(100,3),P(100,5):CLS
15 NUM=0:YEARS=0:WINDOW (-200,-150)-(200,150)
18 SIZE=4:IFLD=INT(FLD(SIZE)/2)
20 PRINT "STAR CLUSTER by Thomas B. Woods"
25 PRINT "for ASTRONOMY Magazine"
55 LOCATE 4,9:PRINT TAB(9)"1. INPUT a set from keyboard"
60 PRINT TAB(9)"2. Generate a RANDOM star set"
70 PRINT TAB(9)"3. LOAD star positions from disk"
80 PRINT TAB(9)"4. SAVE star positions to disk"
90 PRINT TAB(9)"5. LOAD OLD star plot"
100 PRINT TAB(9)"6. OPEN/CLOSE a file for a star plot"
110 PRINT TAB(9)"7. DISPLAY current star coordinate data"
120 PRINT TAB(9)"8. PLOT the stars"
122 PRINT TAB(9)"9. CLEAR current star set"
125 PRINT TAB(8)"10. Change FIELD of view";" (Currently ";
126 PRINT INT(4*FLD(SIZE)/3);" x ";FLD(SIZE);")"
127 LOCATE 9,47:PRINT " (Currently ";
128 IF WFLG THEN PRINT "OPEN)":ELSE PRINT "CLOSED)"
130 LOCATE 14,1:PRINT SPC(50):LOCATE 14,1
135 INPUT "Enter a number... ";W:CLS
140 ON W GOTO 2000,3000,1000,4000,5000,6000,7000,8000,9000,10000
150 GOTO 55
200 INPUT "How many stars";NUM:RETURN
300 K$="":PRINT:PRINT "press any key to return to ";
305 PRINT "menu... (ENTER to plot)":WHILE K$=""
310 K$=INKEY$:WEND:RETURN
400 ON ERROR GOTO 410:FILES "*.PTS":PRINT:FILES "*.PLO"
405 ON ERROR GOTO 0:PRINT:RETURN
410 RESUME NEXT
1000 REM ***LOAD STAR DATA***
1020 GOSUB 1500:OPEN "I",#1,N$:INPUT#1,NUM:FOR I=X+1 TO X+NUM
1030 FOR J=1 TO 3:INPUT#1,P(I,J),V(I,J):NEXT J
1040 INPUT#1,P(I,4):NEXT I:CLOSE#1:X=X+NUM:CLS:GOTO 3100
1500 GOSUB 400:INPUT "Enter POINTS filename (XXXXXXXX.PTS)";N$
1505 CLS:IF N$="" THEN RETURN 3100
1510 IF RIGHT$(N$,4)=".PTS" THEN RETURN
1520 IF RIGHT$(N$,4)=".pts" THEN RETURN ELSE GOTO 1500
2000 REM ***ENTER BY HAND***
2010 GOSUB 200
2020 FOR N=X+1 TO X+NUM
2030 PRINT "Star";N;:INPUT "X-Coordinate";P(N,1)
2040 INPUT "Y-Coordinate";P(N,2)
2050 INPUT "Z-Coordinate";P(N,3)
2060 INPUT "Stellar Mass";P(N,4)
2070 INPUT "X-Velocity";V(N,1)
2080 INPUT "Y-Velocity";V(N,2)
2090 INPUT "Z-Velocity";V(N,3)
2100 CLS:NEXT:GOTO 3090
3000 REM ***GENERATE RANDOM STARS***
3010 RANDOMIZE (TIMER-32768!):GOSUB 200
3015 INPUT"Density Factor (0-100%)";F:F=F/100
```

rapidly. In the case of a direct hit, the computer may even miss the event.

These errors are caused by the sequential nature of the computer. When the machine computes the distances, forces, and accelerations needed to update a star's velocity and position, it does so one star at a time. The large gravitational attractions associated with extremely close bodies result in equally large velocities and displacements. Sometimes the displacement is so great that one star pushes right past another it would collide with if the computer were able to calculate continuous positions.

Special programming in CLUSTER.BAS (at line 8070) reduces the possibility of this occurrence, and, fortunately, close encounters are rare. The problem is not eliminated completely; it is only put off until still closer encounters are reached.

I am a programmer, not a theorist, so I don't claim to know what is supposed to happen when two stars collide. Do they break up, or do they join as one? CLUSTER.BAS sidesteps this issue — the computer beeps when it detects a collision. The stars then continue on their merry way as if nothing had happened.

CLUSTER.BAS is a joy to watch. It was made to experiment with. Before you know it, you'll be asking questions like: "What would happen if I put this star here and that star over there?" And then you can do it.

While NASA will never use CLUSTER.BAS to calculate the trajectory of one of its space vehicles, the program is good at demonstrating gravitational effects on stars. It transforms the abstractions of a physics textbook into something you can actually see on a computer monitor. And, best of all, it's a lot of fun.

Thomas B. Woods is a freelance writer and computer programmer who lives in Jefferson, New Hampshire.

```
3020 FOR N=X+1 TO X+NUM
3030 FOR Y=1 TO 3:P(N,Y)=RND*(IFLD*F)-RND*(IFLD*F)
3040 V(N,Y)=RND-RND:NEXT Y
3070 P(N.4)=RND*4:IF P(N,4)=0 THEN 3070:ELSE CLS:NEXT
3090 X=X+NUM
3100 IF DFLG THEN DFLG=0:GOTO 8000
3110 PRINT "Do you want to add more stars?":GOTO 55
4000 REM ***SAVE STAR DATA***
4020 GOSUB 1500:OPEN "O",#1,N$:PRINT#1,X:FOR I=1 TO X
4030 FOR J=1 TO 3:PRINT#1,P(I,J),V(I,J):NEXT J
4040 PRINT#1,P(I,4):NEXT I:CLOSE#1:CLS:GOTO 3100
5000 REM ***LOAD AND PLOT***
5010 GOSUB 5900:OPEN "I",#3,N$
5015 FOR K=1 TO LOF(3) STEP 20:INPUT#3,Q,R
5020 PSET(Q,R):IF INKEY$="" THEN NEXT K
5030 CLOSE#3:GOTO 7050
5900 GOSUB 400
5903 INPUT "Enter a PLOT filename (XXXXXXXX.PLO)";N$
5907 CLS:IF N$="" THEN RETURN 3100
5910 IF RIGHT$(N$,4)=".PLO" THEN RETURN
5920 IF RIGHT$(N$,4)=".plo" THEN RETURN ELSE GOTO 5900
6000 REM ***OPEN/CLOSE A .PLO FILE***
6005 IF WFLG=1 THEN CLOSE#2:WFLG=0:GOTO 3100
6020 GOSUB 5900:OPEN "O",#2,N$:WFLG=1:GOTO 3100
7000 REM ***DISPLAY COORDINATES***
7005 PRINT "Star";TAB(9)"Position Coordinates";
7007 PRINT TAB(39)"Velocity Vectors";TAB(67)"Stellar"
7010 PRINT " #";TAB(9)"pX";SPC(8);"pY";SPC(8);"pZ";SPC(8);
7015 PRINT "vX";SPC(8);"vY";SPC(8);"vZ";TAB(69)"Mass"
7020 FOR I=1 TO X:PRINT USING "##";I;
7030 PRINT USING "#####.####";P(I,1),P(I,2),P(I,3);
7035 PRINT USING "#####.####";V(I,1),V(I,2),V(I,3),P(I,4)
7040 NEXT I:DFLG=1
7050 GOSUB 300:IF K$<>CHR$(13) OR DFLG=1 THEN CLS:GOTO 3100
7060 LOCATE 1,1:PRINT SPACE$(240):LOCATE 1,1
8000 REM ***PLOT THE STARS***
8010 WHILE INKEY$=""
8020 TIME=1:ERASE ACC:DIM ACC(X,3)
8030 FOR I=1 TO X:FOR J=1 TO X:IF I=J THEN 8120
8050 DIST=(P(I,1)-P(J,1))^2+(P(I,2)-P(J,2))^2
8052 DIST=DIST+(P(I,3)-P(J,3))^2
8055 IF DIST<=3 THEN GOSUB 9100
8060 D=SQR(DIST):FORCE=64*(P(I,4)*P(J,4))/DIST
8070 T=D/(FORCE+D+3):TIME=TIME+((T<TIME)*(TIME-T))
8080 ACC(I,1)=ACC(I,1)+(FORCE*(P(J,1)-P(I,1))/D)
8090 ACC(I,2)=ACC(I,2)+(FORCE*(P(J,2)-P(I,2))/D)
8100 ACC(I,3)=ACC(I,3)+(FORCE*(P(J,3)-P(I,3))/D)
8120 NEXT J
8140 ON ERROR GOTO 410:FOR Y=1 TO 3
8143 V(I,Y)=V(I,Y)+(TIME*ACC(I,Y)/P(I,4))
8147 P(I,Y)=P(I,Y)+V(I,Y):NEXT Y:PSET(P(I,1),P(I,2))
8150 PRINT#2,CINT(P(I,1)),CINT(P(I,2)):ON ERROR GOTO 0
8160 NEXT I:YEARS=YEARS+TIME:WEND
8500 REM LEAVE THE PLOT LOOP
8510 PRINT "Elapsed time:";YEARS;"years":GOTO 7050
9000 REM ***START NEW***
9010 PRINT "Warning!! Star Points will be lost."
9020 PRINT "Enter C for clear or any other key to ";
9030 PRINT "return with original points":INPUT;N$:CLS
9040 IF N$="C" OR N$="c" THEN CLOSE#2:RUN:ELSE GOTO 3100
9100 REM ***COLLISION***
9110 BEEP:LOCATE 1,1:PRINT "HIT!":BEEP
9120 LOCATE 1,1:PRINT SPC(4):RETURN 8120
10000 REM ***CHANGE FIELD SIZE***
10010 PRINT "Current FIELD size is ";
10015 PRINT INT(4*FLD(SIZE)/3);" x ";FLD(SIZE):PRINT
10020 PRINT "1.   13 x   10"
10030 PRINT "2.   40 x   30"
10040 PRINT "3.  133 x  100"
10050 PRINT "4.  400 x  300"
10060 PRINT "5.  800 x  600"
10070 PRINT "6. 1333 x 1000"
10080 PRINT "7. 6666 x 5000"
10090 INPUT "Select FIELD size";SIZE
10100 CLS:IF SIZE<1 OR SIZE>7 THEN SIZE=4:CLS:GOTO 10000
10110 IFLD=INT(FLD(SIZE)/2):JFLD=INT(4*IFLD/3)
10120 WINDOW (-JFLD,-IFLD)-(JFLD,IFLD)
10130 GOTO 20
```

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The cost is $14.95 and the product number is #18035. Send your order for CLUSTER.BAS to: ASTRONOMY Order Dept., 1027 North 7th Street, Milwaukee, WI 53233. Include $1 for postage and handling in the United States ($1.50 in foreign countries). Wisconsin residents should add 5 percent sales tax.

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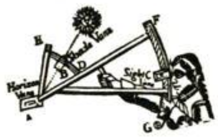

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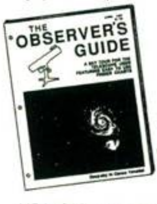

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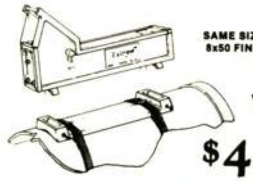
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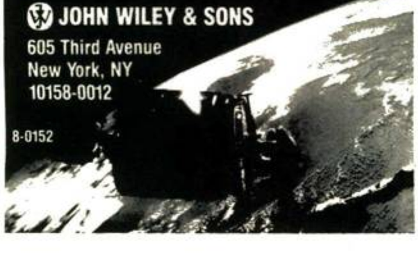

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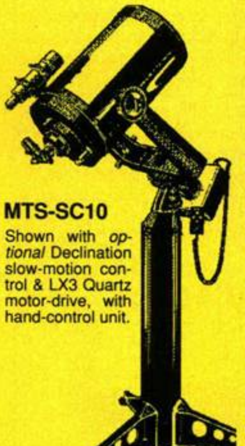

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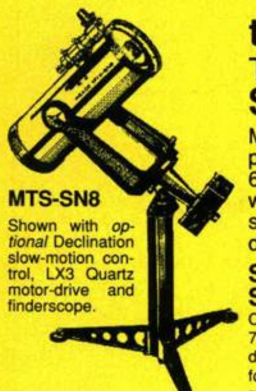

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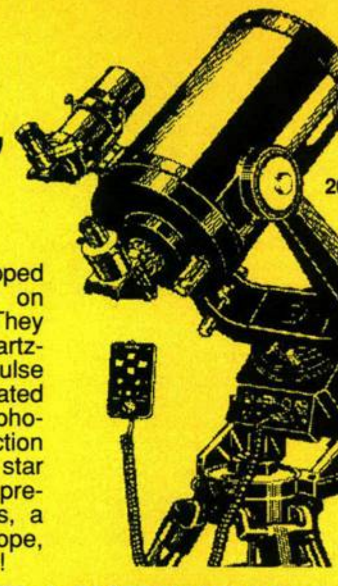

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AstroNews

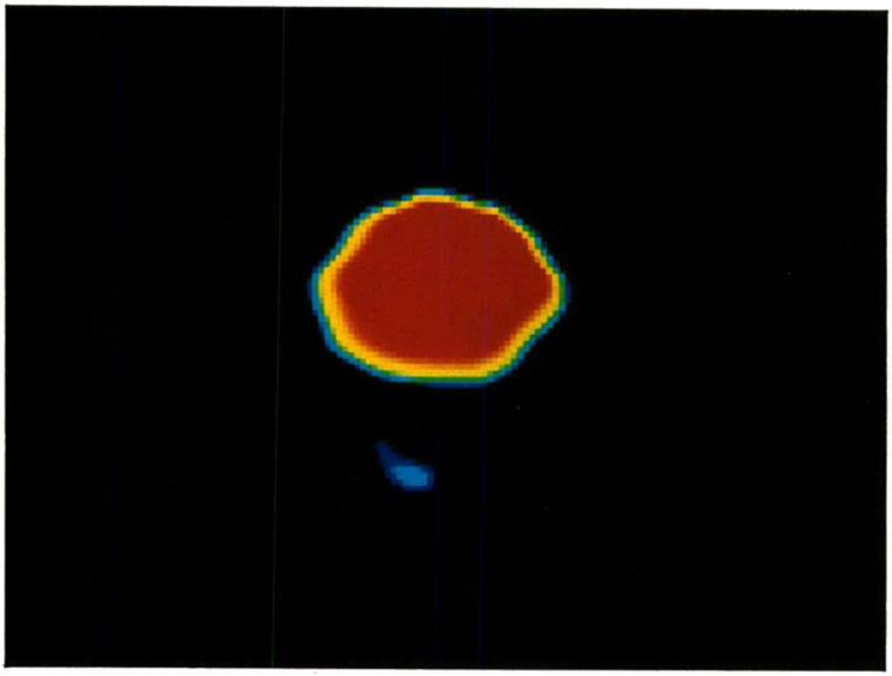
Nature of Supernova 1987A, Mysterious Companion Discussed at AAS Meeting

Now that supernova 1987A is growing dimmer, astronomers are realizing that its previous behavior was not as bizarre as they had originally thought. And yet the discovery of a totally unexpected, bright companion object to the supernova shows that a great deal remains to be learned. These are just two of the supernova highlights discussed at the joint meeting of the American Astronomical Society and the Canadian Astronomical Society in Vancouver, British Columbia, June 14-18.

There is a growing consensus among astronomers working on the supernova that 1987A is *not* as unusual an object as everyone had at first feared. This is a significant point in itself: If 1987A turned out to be a unique supernova with no discernable relationship to any other, our knowledge of supernovae as a class would not increase at all. As it is, 1987A offers astronomers an unprecedented opportunity to learn more about all supernovae.

Light output from the supernova finally reached a peak around May 20 at a visual magnitude of about 2.9, and it is now fading. Many theorists suspect the energy output now comes from radioactive decay, the same process that powers Type I supernovae.

Why was 1987A dimmer and why did it take so much longer to reach maximum compared with other Type II supernovae? The answer to this question hinges on the nature of the progenitor. No one doubts anymore that the blue supergiant Sanduleak −69°202 was the star that exploded. However, most theories of Type II supernovae predict the progenitor should have been a red supergiant because only this kind of star can account for the brightness of typical Type IIs.



Astronomers studying supernova 1987A are perplexed by the enigmatic companion detected near the supernova with the 4-meter telescope at the Cerro Tololo Interamerican Observatory in Chile. The companion appears smaller than the supernova in this image only because it is much fainter than 1987A. Theorists have not been able to determine what type of object the companion might be or in what way it is interacting with the supernova. Harvard-Smithsonian Center for Astrophysics image.

Blue supergiant progenitors have not been seen before because we are much more likely to see the brightest Type II supernovae than the dimmest. If a blue supergiant were to explode, the expansion would cool the star and make it substantially fainter. In essence, we don't observe many Type II supernovae arising from blue supergiants because they are much fainter than supernovae arising from red supergiants; therefore, we see them only when they occur in relatively nearby galaxies. There are several possible reasons a star near the end of its life might be blue and not red, among them a previous episode of mass loss or a low abundance of elements heavier than helium, which is typical of stars in the LMC.

The most surprising news concerning the supernova presented at the Vancouver meeting had to be the detection of an optical companion. Costas Papaliolios and Peter Nisenson of the Harvard-Smithsonian Center for Astrophysics used the 4-meter telescope at Cerro Tololo in Chile and speckle interferometry to discover a companion just 60 milliarcseconds away from the supernova. This corresponds to an actual distance of about 17 light-days (the distance light travels in 17 days moving at a rate of 300,000 kilometers per second). Their observations were subsequently confirmed by a group from Imperial College in London using the Anglo-Australian Telescope.

The companion is one-tenth as bright as the supernova and five to six magnitudes brighter than Sanduleak −69°202 was before the explosion. Apparently this is some type of object being energized by the explosion, but none of the theorists present had a convincing theory for what that object might be.

Many of the scientists expect real fireworks when the supernova's shock wave reaches the object. Traveling at a speed of about 30,000 kilometers per second (one-tenth that of light), the shock wave should reach it some five to six months after the explosion. In the meantime more speckle observations will be made, and some speckle observations already completed will be computer analyzed.

'Ring of Truth' Science Series Premieres This Fall

"The Ring of Truth," a six-part series that examines how science knows what it knows, will premiere on Public Broadcasting Service stations October 20.

Phil Morrison, a physicist at the Massachusetts Institute of Technology and the creator and host of the series, will present the inner workings of science by using everyday experiences to explain the principles behind scientific theories.

The show will cover scientific instruments, mapmaking, the grand laws of constancy, the geological record embedded in landmasses and the ocean floor, the graininess of matter, and the weight of darkness.

The first and sixth parts of the series focus on astronomy. On the first night Morrison will use the development of the telescope as the central story to demonstrate how scientists' tools shape our world view.

The final episode contrasts the astrophysical quests of two astronomers: Is the mass of the universe made up of 90 percent hydrogen, as Cecilia Payne theorized at the end of World War I, or of something we can't see, left over from the beginning of the universe, as Vera Rubin at Palomar Observatory currently theorizes.

Remnant of Supernova May Be Visible

Light from supernova 1987A in the Large Magellanic Cloud will reflect off surrounding dust grains, forming a bright supernova remnant that could remain visible for many years, according to astronomer Brad Schaefer of NASA's Goddard Space Flight Center. The resulting nebula will be visible next spring.

When a supernova explodes, it produces an expanding shell of light that illuminates dust grains as it travels outward. Because the light reflected by dust takes longer to reach us than direct light from the supernova, the phenomenon is called supernova "light echo." Schaefer's calculations show that, depending on the geometry of how dust clouds reflect the supernova's light, the remnant nebula around the supernova could become bright enough to be visible in binoculars.

Schaefer explains: "When the supernova has faded sufficiently, the echo should be visible in small telescopes and binoculars. Best visibility will occur when the supernova becomes fainter than the echo. It is difficult to predict when this will happen, but a year after discovery seems reasonable."

How bright will the light echo be? Schaefer predicts that "the echo will appear as a centrally condensed nebula with a diameter of 100 seconds of arc and an integrated magnitude of 10.2." In other words, the supernova light-echo nebula will appear about the same size and brightness as the Ring Nebula (M-57), an object easily visible in small amateur telescopes.

Massive, Dark Galaxy Found in Void

Astronomers have discovered what they believe is the largest, darkest, most gas-rich spiral galaxy known in a "void" beyond the Virgo Cluster of Galaxies. Discovered by accident on long-exposure photographic plates, the object, called Malin 1, appears to still be forming.

Most of the visible galaxies are distributed in clusters, strings, or "pancakes" surrounding regions in space that appear to be devoid of matter. But the discovery of a massive galaxy in such a void implies that the voids in space may not be empty after all.

Malin 1 first fell under scrutiny in late 1985 during a survey in the Virgo Cluster for dwarf galaxies — unusually faint, star-poor elliptical galaxies too dim to be seen at great distances. Conducted with the United Kingdom's 1.2-meter Schmidt telescope at Siding Spring, Australia, the survey used a photographic amplification technique designed by astronomer David Malin for detecting exceptionally faint galaxies.

In February 1986 Malin 1 was among forty faint dwarf galaxy candidates chosen for further study with a charge-coupled device camera attached to the 2.5-meter telescope at Las Campanas in Chile. The CCD photometry revealed that the galaxy had a bright nucleus and a spiral structure.

Then in May 1986 researchers using the 5-meter telescope at Palomar Observatory found that Malin 1's nucleus is receding at a velocity twenty-five times faster than the Virgo Cluster. This implies that the galaxy is twenty-five times farther away than the Virgo Cluster.

Hence, far from being a modest dwarf galaxy, Malin 1 appears to be an enormous system 220 megaparsecs away. According to astronomers Greg Bothun of the University of Michigan, Christopher Impey of Steward Observatory at the University of Arizona, David Malin of the Anglo-Australian Observatory at Sydney, Australia, and Jeremy Mould of the Cali-

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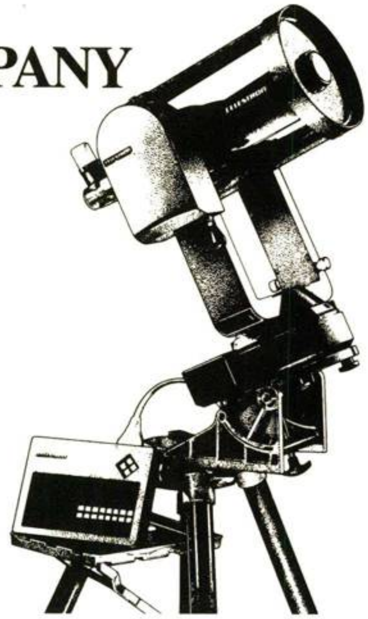

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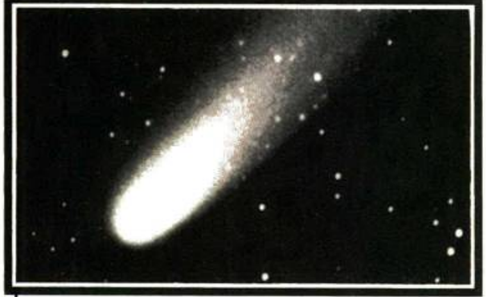

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fornia Institute of Technology, the hydrogen disk of Malin 1 is 236 kiloparsecs in diameter (almost two-and-a-half times the diameter of the halo of the Milky Way). The galaxy is one hundred times darker than normal spiral galaxies and has at least five times the hydrogen abundance of any known galaxy.

Apparently Malin 1 has a massive reservoir of star-making material, but star formation has not yet begun, so the disk remains faint. According to Impey, it will take a couple of years to obtain enough spectra from Malin 1's stars to discern whether those stars are young. If they are young, Malin 1 would be classified as a true protogalaxy.

"If this galaxy is really forming — and that's a very big 'if' — it has great implications for galaxy formation," says Impey. "People reasonably enough have chosen to look at [galaxies with] very high red shifts [i.e., at great distances] for very young galaxies — primeval galaxies or protogalaxies — because there must have been some epoch early in the universe when most galaxies did form.

"But there is nothing in the theory of spiral galaxy formation that says a spiral disk couldn't take billions of years to form. It's not unreasonable to theorize that spiral galaxies might be forming right now very close to us."

Another implication of this discovery, says Impey, is that voids in space may harbor many objects like Malin 1. Moreover, some of the missing mass of the universe might be found in these objects.

"We didn't expect to find anything like this," Impey says, referring to Malin 1. "This galaxy is far removed from our ideas of what a normal galaxy should look like. There could be more of these things that haven't been discovered yet."

IRAS Data Provide Clues to Pluto's Size, Atmosphere

Astronomers have found new evidence for a "substantial" atmosphere of Pluto. A report published in *Nature* (May 13, 1987), based on analysis of data from the *Infrared Astronomical Satellite* (*IRAS*), also provides significant clues about Pluto's size.

Jet Propulsion Laboratory astronomers Edward F. Tedesco, Glenn J. Veeder, and R. Scott Dunbar, and University of Arizona astronomer Larry A. Lebofsky undertook the *IRAS* data analysis. The astronomers found that *IRAS* observations of Pluto also suggest that the planet is 2,200 kilometers in diameter and that Pluto's moon Charon is 1,300 kilometers in diameter.

To determine this, the astronomers coupled the *IRAS* infrared data with theoretical models of how the Pluto-Charon system should behave at Pluto's distance from the Sun. The results reduce the uncertainty planetary astronomers have about the sizes of Pluto and Charon.

In addition, the *IRAS* researchers found that Pluto is much higher in infrared emission, which means Pluto has a higher temperature than previously suspected. This suggests that Pluto is not a barren chunk of rock like an asteroid, which would allow heat to quickly radiate into space, but that Pluto's methane atmosphere is "substantial," retaining heat in the planet's atmosphere.

Along with having a moon, a substantial Plutonian atmosphere supports the notion that Pluto is indeed a planet and not, as some astronomers believe, a lost Neptunian moon or a vagabond asteroid.

Asteroid Impact Evidence Found around the World

The asteroid impact theory for the mass extinction at the Cretaceous-Tertiary boundary 66 million years ago has been strengthened now that shocked quartz grains, linked exclusively to impact by an extraterrestrial object, have been confirmed at several sites around the world.

Bruce Bohor, Peter Modreski, and Eugene Foord of the U.S. Geological Survey reported in *Science* (May 8, 1987) that they found shocked quartz grains in the Cretaceous-Tertiary border at seven sites — the central North Pacific, New Zealand, southern Spain, two in Denmark, and two in northern Italy — in addition to their initial discovery in Montana.

The discovery confirms Luis Alvarez's theory that a large meteoroid or asteroid hit Earth at the end of the Cretaceous period, threw up a dust cloud that circled the globe and blocked sunlight, and caused major extinctions. The discovery also suggests that shocked quartz should be found at every Cretaceous boundary layer that contains iridium.

Iridium in abnormally high amounts found at the Cretaceous-Tertiary boundary layers was the first evidence for an asteroid impact. Iridium has been found at more than seventy-five sites. Now that shocked quartz has been found at sites with high concentrations of iridium, the impact theory has overtaken the volcanism theory, which proposes that the extinctions were caused by a period of abnormally intense terrestrial volcanism. Volcanic dust would, according to this theory, block sunlight and alter Earth's climate.

Volcanoes haven't been shown to produce the type of shocked quartz found at the Cretaceous-Tertiary boundary, and volcanism can't produce a force strong enough to spread quartz grains around the world. Asteroid impact, on the other hand, would release instantly and at one spot the energy of about 100 trillion tons of TNT.

Scientists are still searching for evidence of shocked quartz and iridium at other geological period boundaries, which would verify that the impacts and the extinctions are periodic, occurring every 26 million years.

ASTRONOMY AstroCalendar

August 21-23
5th Connecticut River Valley Astronomers' Conjunction (three-day weekend of Milky Way viewing, lectures, camping), Northfield Mountain Environmental Center, Northfield, Massachusetts. Contact: Jack Megas, 311 Surrey Road, Springfield, MA 01118.

August 29-September 27
Space Imagery Exhibit (celestial photography, space equipment, sponsored by the City of Lancaster Museum/Art Gallery), Lancaster, California. Contact: Norma Gurba, 44801 North Sierra Highway, Lancaster, CA 93534. Phone: (805) 948-8655.

September 2-October 15
"25 Years of Space Photography" (140 photographs taken by unmanned spacecraft; organized by the Baxter Art Gallery at the California Institute of Technology and sponsored by IBM), Lowe Art Gallery, University of Miami, Coral Gables, Florida. Contact: Andrea Kirsh or Ira Licht, 1301 Stanford Drive, Coral Gables, FL 33146. Phone: (305) 284-3553.

September 18-20
8th Annual Astrofest (sponsored by the Chicago Astronomical Society), Camp Shaw-Naw-Nas-See, sixty miles south of Chicago, Illinois. Contact: Astrofest, P.O. Box 596-A, Tinley Park, IL 60477.

September 18-20
September Starfest (sponsored by the Southern Cross Astronomical Society, Inc.), Florida International University-Tamiami Campus, Miami, Florida. Contact: Southern Cross Astronomical Society, 690 Allendale Road, Key Biscayne, FL 33149. Phone: (305) 661-1375.

September 25-26
N.I.A.G. Fest '87 (sponsored by the Northern Indiana Astronomical Group: Warsaw, Michiana, and Fort Wayne Societies). Holiday Inn, Warsaw, Indiana. Contact: Alan Mitterling, RR #3, Box 331A, Warsaw, IN 46580.

October 2-4
AstroAssembly 1987/Northeast Regional Astronomical League Convention (sponsored by Skyscrapers, Inc., the Astronomical Society of Rhode Island), Seagram Memorial Observatory, North Scituate, Rhode Island. Contact: Brian Magaw, Town Farm Road, P.O. Box 325, Pascoag, RI 02895. Phone: (401) 568-8424.

October 3-4
3rd Meteor Space Meeting, Amsterdam, Holland. Contact: Mark P. Traa, *Meteor Magazine*, Mosbeek 26, 5501 BD Veldhoven, Holland.

October 8-10
Great Plains Planetarium Association Meeting, Omnisphere Earth-Space Center, Wichita, Kansas. Contact: Jose Olivarez, Omnisphere Earth-Space Center, 220 South Main, Wichita, KS 67202.

October 15-27
Joint Meeting of the Rocky Mountain and Pacific Planetarium Associations, Fleischmann Planetarium, Reno, Nevada. Contact: Arthur W. Johnson, Jr., Fleischmann Planetarium, University of Nevada, Reno, NV 89557.

October 18-31
Peru Revisited (three-part field trip sponsored by the Astronomical League). Leaves from Miami. Registration deadline: September 16. Contact: Cynthia Crittenden or Laura Stanley, Travel and Transport, St. Joseph, MO. Phone: 1-800-821-9010, in Missouri 1-800-892-9035.

October 23-25
9th Annual Astronomy Jamboree, Custer Institute, Southold, Long Island, New York. Contact: Tom Carey, Vanderbilt Planetarium, Centerport, Long Island, New York 11721. Phone: (516) 757-7501.

October 23-25
Deep South Regional Stargaze (sponsored by the Jackson Astronomical Association), Percy Quin State Park, McComb, Mississippi. Contact: Jeff Sommers, 414 Woody Drive, Jackson, MS 39212. Phone: (601) 982-2388 days, (601) 372-2275 evenings.

October 24
Astronomy Rendezvous and Conference 1987 (sponsored by the Twin City Amateur Astronomers), Illinois State University, Normal, Illnois. Contact: Carl J. Wenning, Physics Department Planetarium, Illinois State University, Normal, IL 61761-6901. Phone: (309) 438-8758.

October 29-31
Great Lakes Planetarium Association Meeting, Pierce Junior High School, Merillville, Indiana. Contact: Gregg L. Williams, Pierce Junior High School, 199 East 70th Avenue, Merillville, IN 46410.

AstroCalendar notices must be submitted at least four months in advance of the date of the event.

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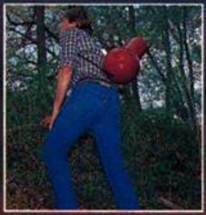

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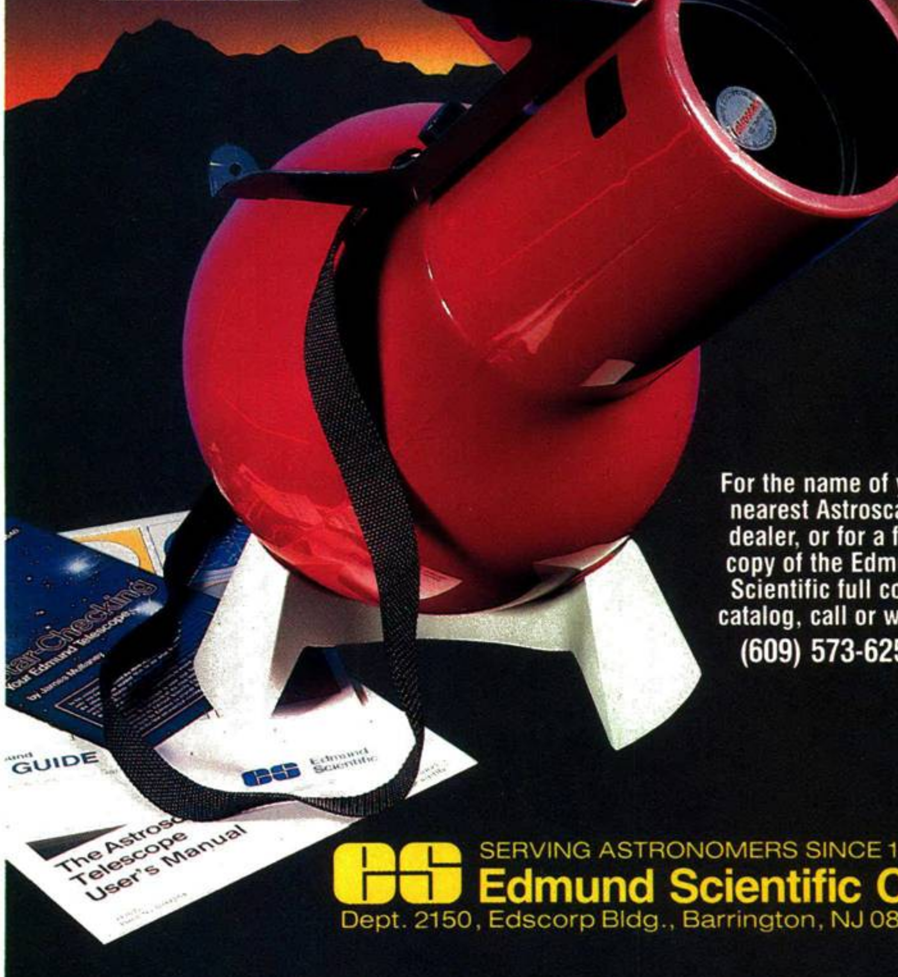
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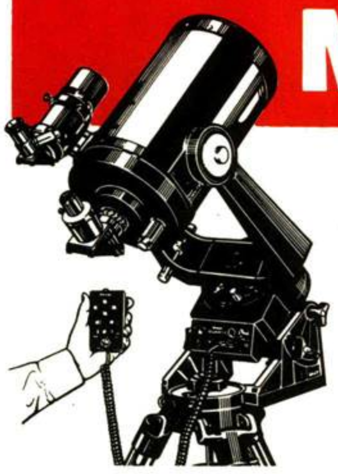

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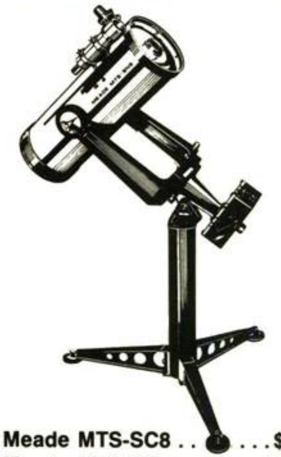

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ASTRONOMY Reviews

The Great Dying
Kenneth J. Hsu
292 pages, hardcover, $17.95
ISBN 0-15-136904-6
Harcourt Brace Jovanovich (1986)

'Twas a fine day in April, 65 million years ago, when the trillion-ton asteroid came sailing out of the sky. . . .

The asteroid, five miles across, was invisible until atmospheric friction heated its skin during the last seconds of its journey. Then the asteroid slammed down with unbelievable force somewhere on land in Earth's Northern Hemisphere.

In the target zone a vast fireball of vaporized rock climbed swiftly into the sky, mushrooming when it reached the stratosphere. At the base, intense heat and hurricane-force winds toppled forests over thousands of square miles and set them alight, which contributed to the firestorm that was spewing soot dozens of miles into the air.

After the fires burnt out, the cold came. For three months the skies over much of the Earth were as dark as midnight — all day, every day — while the dust and soot settled like a ghastly black snowfall. Earth's surface probably saw two hundred inches of precipitation every day — and thanks to the chilly temperatures under the Sun-snuffing clouds, most of the precipitation came down as snow. Strange photochemical reactions ensured that all precipitation was highly acidic.

When the clouds cleared, the Earth lay enshrouded under a mantle of dingy snow. But the chill in the air didn't last. The mass mortality on the land and in the oceans dumped immense quantities of carbon dioxide into the atmosphere — up to triple the present level, which is already elevated because of human activity. Soon the greenhouse effect heated the surface of the Earth to hotter than normal (though not as hot as Venus is today).

The biological devastation was greater in the Northern Hemisphere than in the Southern, which is why researchers surmise the impact came during the northern spring. Southern species were already preparing for their winter and thus gained an edge on survival, while northern species were unprepared for a re-imposition of winter.

In the oceans, chemical poisoning of the surface layers severed food chains, bringing death to many species indirectly. On land, where the interrelations were more complex, the repercussions were worse. Many species couldn't endure the change. Everyone's favorite geological riddle —"What killed off the dinosaurs?" — now appears to have a fairly straightforward answer. If they weren't done in by the brutal "nuclear winter," the saurians probably found the new climate too hot. Either they succumbed outright in the heat or, more likely, they lost the ability to reproduce normally. The result — a population crash — is the same in both cases, though the latter course runs a little more slowly.

Despite what many writers in the past have claimed, the dinosaurs weren't "failing." They and countless other species were going along like gangbusters — evolving, diversifying, and, in general, successfully being themselves. What happened was an environmental stress that simply dumped too much change on them too fast for them to adapt. And so most of them died — as we might under similar conditions.

When the natural weather systems finally reasserted themselves with the help of the waste products from the few surviving species, the result was a burst of "speciation" — the creation of new species — that was almost explosive. In the process the dominant land animals changed from saurian to mammalian. Ever so slowly the world as we know it today took shape.

Such a major change in dominant life form had happened twice before, and in both cases geological evidence points to a massive impact at the changing point. When the soft-bodied animals such as those of the Ediacara fauna group were wiped out 600 million years ago, trilobites with exoskeletons arose in the aftermath. Likewise, when an impact killed off many species at the start of the Mesozoic era 250 million years ago, dinosaurs "quickly" resulted. What happened 65 million years ago at the boundary between the Cretaceous and the Tertiary periods is just the same old story — except that mammals were the beneficiaries this time.

Kenneth Hsu is a geologist who became interested in the "terminal Cretaceous event" (as it is known) about a decade ago. He has written an absorbing book for the layman about the evolution of the impact model from the point of view of someone who's been involved in the subject almost from the beginning.

Why should amateur astronomers bother with such a book? If you've ever been pestered by nonastronomical friends who have heard that asteroids or comets had a hand in the "death of the dinosaurs," you know why. This is a clearly written, up-to-date account that, unlike similar books by professional astronomers, covers in detail the geological, biological, and chemical changes that took place. It shows how the theory for a massive impact, crazy as it seemed at first, slowly won acceptance and pointed the way to more details that, often as not, checked out.

The book also has an interesting second theme touching on Hsu's own intellectual development. When in the course of his research he found that the Mediterranean Ocean dried up completely some 6 million years ago, he was forced to admit that classical uniformitarianism — "the present is the key to the past" — wasn't much help in understanding what happened. This in turn got him thinking about a long-outmoded school of thought in geology called catastrophism.

Catastrophism, the antithesis of uniformitarianism, has been a naughty word in geology for about 150 years now, thanks to its early proponents who, like many creationists still do, interpreted every Earth feature in terms of Noah's flood. And although geologists have learned to accept that sometimes changes happen so suddenly they can be considered catastrophic, the dominant reasoning in the field still allows only gradual changes at rates similar to what we see operating today. Hsu appears delighted about the continuing work on the impact models that is forcing geology to confront the boogieman thumping the closet walls for a century and a half.

Darwin also gets dragged into the argument and here I'm not sure I agree with Hsu, though I say this with temerity. Hsu's argument may be more subtle than I perceive, but he appears to say that since impacts are such devastatingly sudden and catastrophic events, there's no time for natural selection to work. However, this seems true only if you hew to a very narrow, slow-working definition of natural selection. To me, "fittest to survive" means just that, come what may. I don't see why natural selection can't operate through a catastrophe, even if a lot of luck is involved. I realize much scorn has been heaped on the circular reasoning in the catch phrase "survival of the fittest," because we identify fitness with having survived. But surely surviving a catastrophe counts at least as some kind of fitness?

Anyway, my quibble is minor and doesn't impinge on the book's many good qualities. The book's strongest point may be the way it gets you meditating on extinctions, past and future. Though I may be alone, I'm quietly cheered by the recent research into the nuclear winter scenario, which has evolved out of studies of the Cretaceous impact. Not that I want nuclear winter to happen, but the research has simultaneously given us a useful handle on part of our planet's past and, at the same time, has shown what a shut-ended future we face if we don't act responsibly in our own affairs.

Ediacarans, trilobites, dinosaurs — none of these species could avoid what happened. The fates of these species were the product of probabilities: that the Earth would be at a certain place and time when a big rock was there too. But getting conked by a piece of the solar system is at least an honorable end, however randomly it may occur.

We're in a different position. We now have the ability to understand such a catastrophe and perhaps do something about it if the celestial one-armed bandit sends us three lemons again. But if we fail to avert the disaster — well, something would probably evolve to replace us.

On the other hand, we also have the Bomb. And given what we've learned about the geologic past, doing a similar number on ourselves would be downright stupid. *Robert Burnham.*

Highlights of Astronomy, Volume 7
J. P. Swings, ed.
894 pages, cloth, $149
ISBN 90-277-2278-1
D. Reidel (1986)

A compendium of papers presented at the IAU 29th General Assembly in 1985, *Highlights* is a fundamental reference for recent astronomical research. Among the papers are "Photometry of the Recent Eclipse of Epsilon Aurigae" by Robert E. Stencel, "The Concept of Young Populations" by Gosta Lynga, and "Centenary of S Andromedae" by Sidney van den Bergh.

The Cambridge Photographic Atlas of the Planets
G. A. Briggs and F. W. Taylor, eds.
256 pages, paper, $14.95
ISBN 0-521-31058-X
Cambridge University Press (1986)

This paperback release of 1982's *Photographic Atlas* includes a new chapter on the *Voyager* mission to Uranus.

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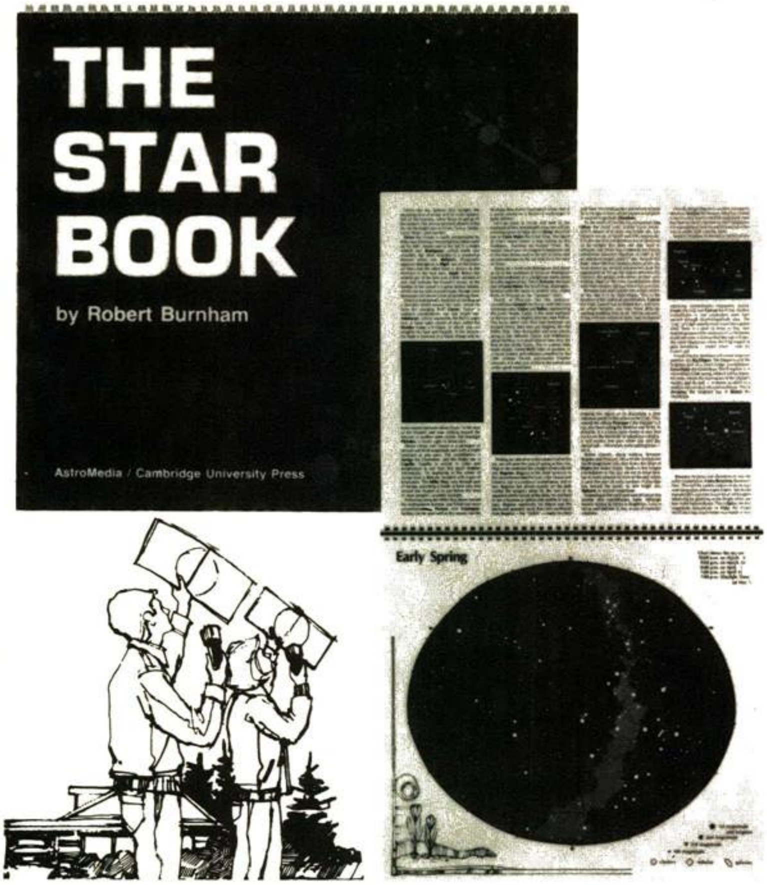
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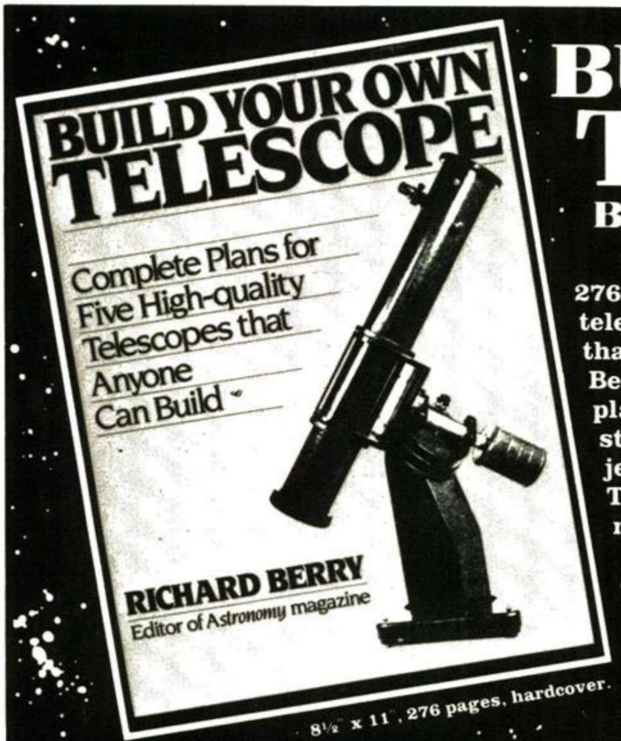
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The Almanac for Computers 1987
LeRoy E. Doggett and
Helena I. Guertler, eds.
100 pages, paper, no price given
United States Naval Observatory (1986)

What time will the Moon rise on November 15? Will Mercury and Venus pass within 5° of each other within the next year? When does twilight end on June 29? *The Almanac for Computers 1987* provides data for answering these and similar questions in positional and navigational astronomy for users of microcomputers.

Polycyclic Aromatic Hydrocarbons and Astrophysics
A. Leger, L. d'Hendecourt and
N. Boccara, eds.
402 pages, cloth, $74.50
ISBN 90-277-2361-3
D. Reidel (1986)

This is the proceedings from the 1986 NATO Advanced Research and Centre National de Research Scientifique Workshop held in Les Houches, France. Among the papers are "Hydrogenated Amorphous Carbon in the Planetary Nebula NGC 7027" by J. H. Goebel, "Polyaromatic Hydrocarbons and the Condensation of Carbon in Interstellar Winds" by R. Keller, and "Carbon Components of Interstellar Dust" by J. M. Greenberg, M. S. De Groot, and G. P. Van der Zwet.

Quantum Concepts in Space and Time
R. Penrose and C. J. Isham, eds.
358 pages, cloth, $80
ISBN 0-19-851972-9
Oxford University Press (1986)

Included in this book are the proceedings from a 1984 conference on quantum theory held at Lincoln College in Oxford, England.

Heavenly Clockwork, 2nd edition
Joseph Needham, Wang Ling, and
Derek J. de Solla Price, eds.
266 pages, cloth, $59.50
ISBN 0-521-32276-6
Cambridge University Press (1986)

Subtitled "The Great Astronomical Clocks of Medieval China," this book examines Chinese astronomical machinery and its contribution to the understanding of the cosmos.

The preface of *Heavenly Clockwork* states: "it is generally allowed that the invention of the mechanical clock was one of the most important turning-points in the history of science and technology. Not only was it the earliest complex device, heralding a whole age of machine-making, but also its regular imitation of the natural motion of the Sun and the heavens fascinated men and exerted no small influence on their philosophy and theology."

Star Gazing through Binoculars
Stephen Mensing
230 pages, paper, $14.95
ISBN 0-8306-2703-0
TAB Books (1986)

An introductory guide to observing the sky with binoculars, this book covers information on equipment, planets, comets, meteors, Earth-orbiting satellites, stars, deep-sky objects, and astronomical data.

The New Astronomy
Nigel Henbest and Michael Marten
240 pages, paper, no price given
ISBN 0-521-31057-1
Cambridge University Press (1986)

This is a paperback edition of the original *The New Astronomy*, which was published in 1983. It covers various aspects of astronomical imaging current at that time.

To Space & Back
Sally Ride with Susan Okie
96 pages, cloth, $14.95
ISBN 0-688-068159-1
Lothrop, Lee & Shepard Books (1986)

To Space & Back is astronaut Sally Ride's pictorial story of space flight in diary form, illustrated with many in-flight photographs. The book is written in a basic style and set in large type so youngsters can enjoy it.

Quasar Astronomy
Daniel W. Weedman
217 pages, cloth, $39.50
ISBN 0-521-30318-4
Cambridge University Press (1986)

Written on a graduate student level, this book is an overview of the field of quasar research in the 1980s. Included are chapters on technology for studying quasars, quasar surveys, cosmology, luminosity functions, evolution, and quasar structure.

Astrometric Techniques
Heinrich K. Eichhorn and
Robert J. Leacock, eds.
838 pages, cloth, $144
ISBN 90-277-2256-0
D. Reidel (1986)

Astrometric Techniques is the proceedings of the 1984 International Astronomical Union meeting on astrometry held at the University of Florida in Gainesville. Among the papers are "Astrometry of Star Clusters" by Kyle M. Cudworth, "Speckle Interferometry in Astrometry" by Harold A. McAlister, "The New Index Catalogue of Visual Double Stars" by Charles E. Worley and Geoffrey G. Douglas, and "The Preparation and Distribution of Machine-Readable Astrometric Data" by Wayne H. Warren, Jr.

Your Future in Space
Penelope and Raymond McPhee
143 pages, paper, $14.95
ISBN 0-517-564181
Crown Publishers (1986)

This book is a colorful photographic guide to life at the U.S. Space Camp in Huntsville, Alabama. It is aimed at kids, but adults also may find the descriptions of astronaut training interesting.

Dynamical Spacetimes and Numerical Relativity
Joan M. Centrella, ed.
465 pages, cloth, $49.50
ISBN 0-521-32860-8
Cambridge University Press (1986)

Dynamical Spacetimes is the proceedings of a conference held at Drexel University in Philadelphia in 1985. Among the papers are "Relativistic Stellar Dynamics on the Computer" by Stuart L. Shapiro and Saul A. Teukolsky, "Nonlinear Gravitational Waves and Inhomogeneous Cosmologies" by Joan M. Centrella, and "Approximate Methods for Black Hole Collisions" by D. M. Eardley.

Birth and Evolution of Massive Stars and Stellar Groups
W. Boland and H. Van Woerden, eds.
377 pages, cloth, no price given
ISBN 90-277-2135-1
D. Reidel (1986)

This is the proceedings volume from a 1984 symposium held in Dwingeloo, the Netherlands, to honor the eminent astronomer Adrian Blaauw. Among the papers are "Observable Consequences of Star Formation in Molecular Clouds" by George H. Herbig, "Supernovae and Pulsars" by Virginia Trimble, "Formation of Massive Stars and the Structure of Galaxies" by Bruce G. Elmegreen, and "Blaauw's Scientific Work" by Jan H. Oort.

Properties and Interactions of Interplanetary Dust
R. H. Giese and P. Lamy, eds.
444 pages, cloth, no price given
ISBN 90-277-2115-7
D. Reidel (1986)

Interplanetary Dust is the proceedings from a 1984 colloquium held at Marseille, France.

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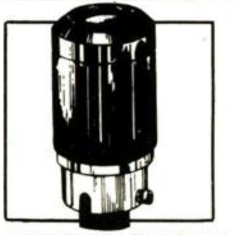

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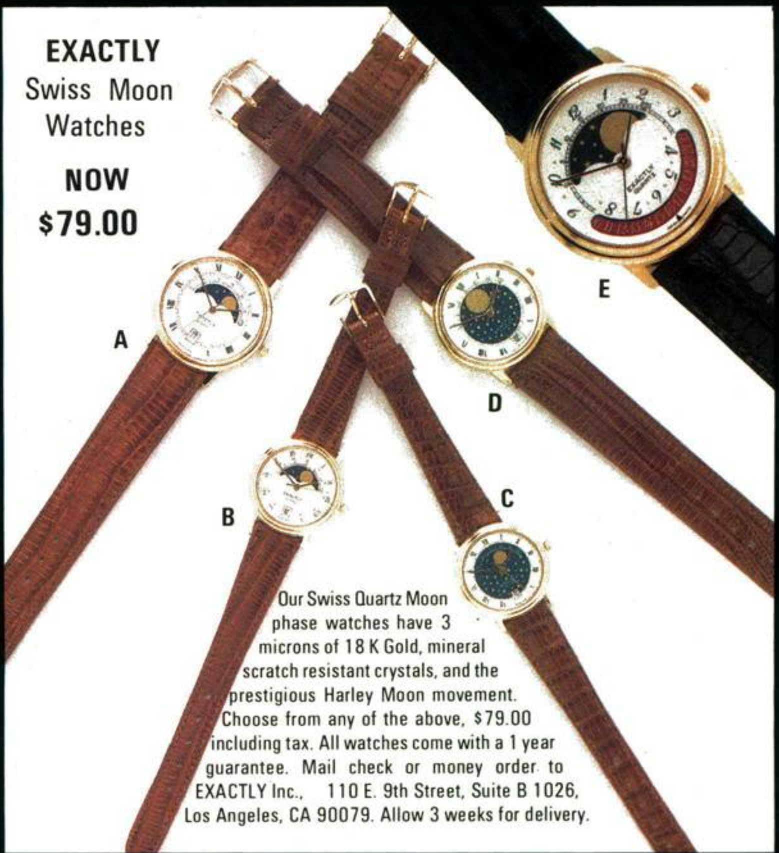

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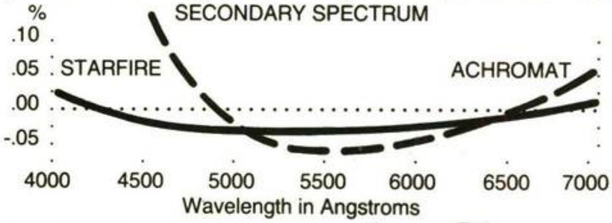

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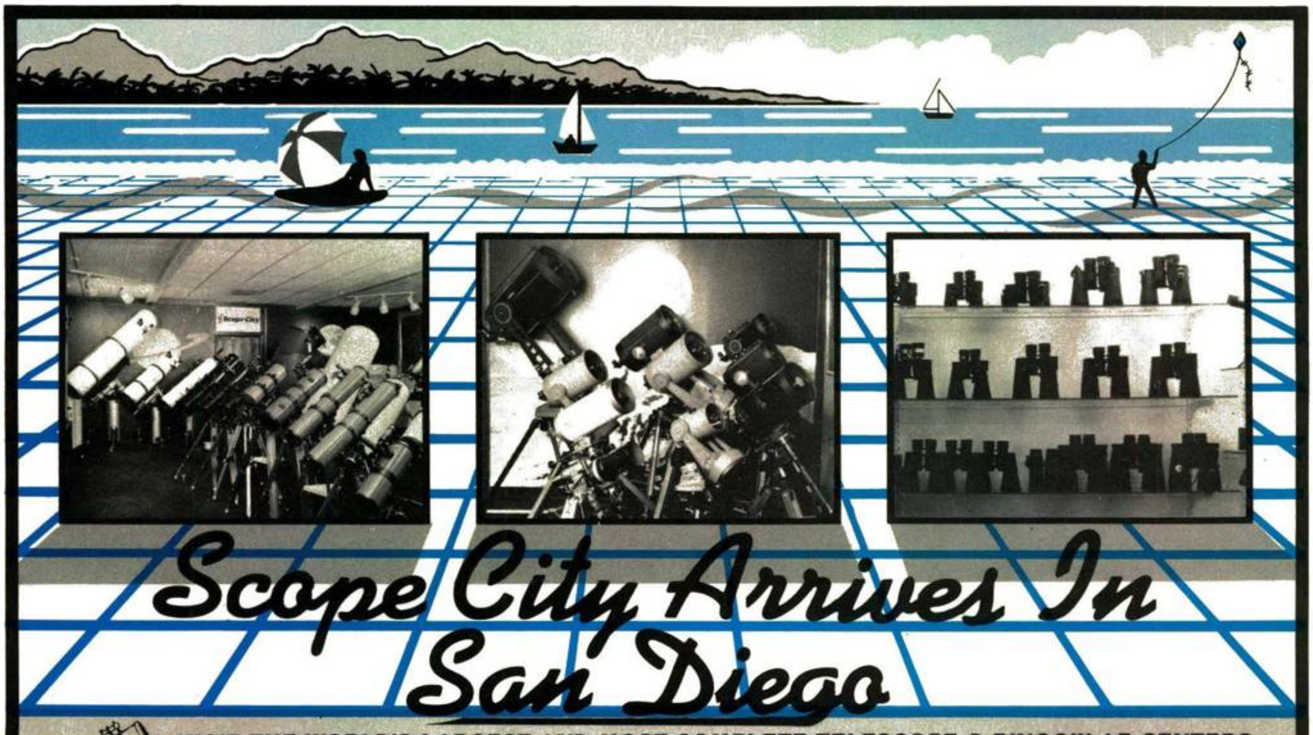

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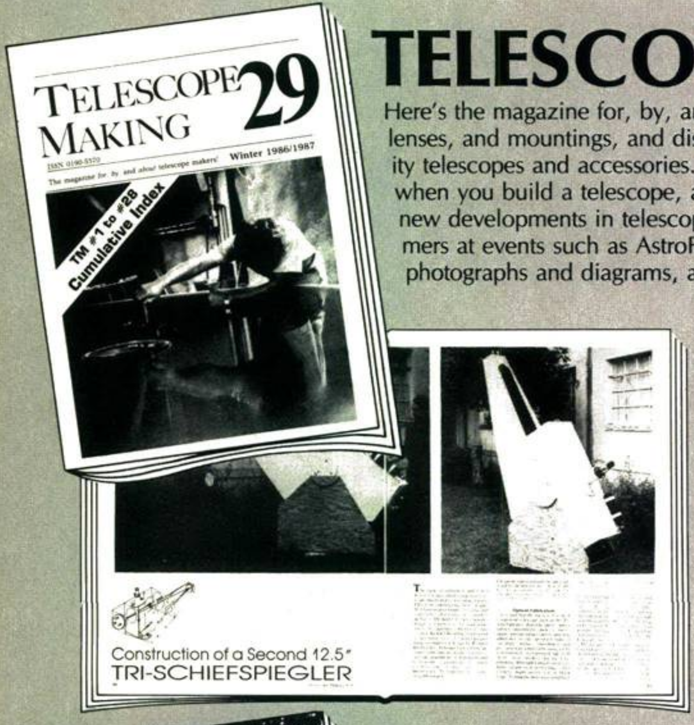
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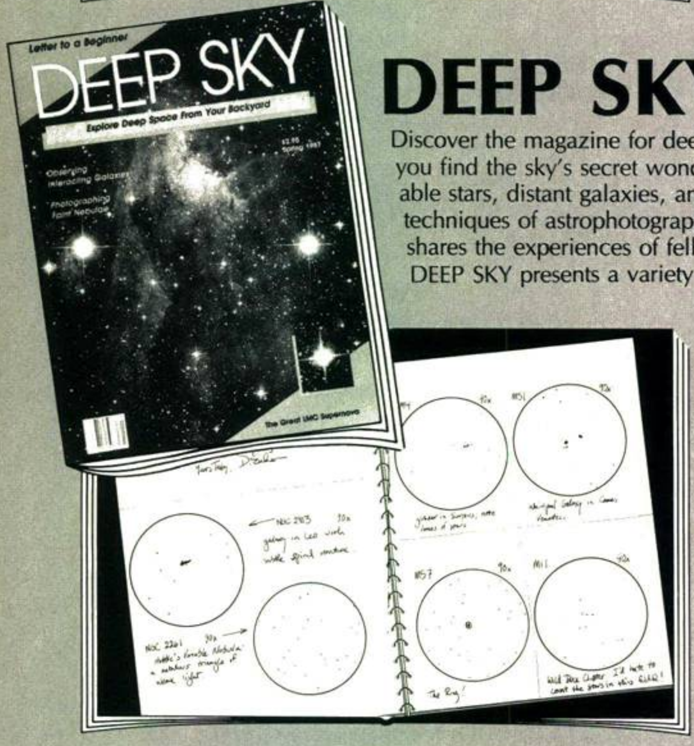
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Observing Comet Halley's Near-Nucleus Features

BY STEPHEN LARSON AND DAVID H. LEVY

As the Sun comes up over the horizon, a patch of Comet Halley's surface suddenly explodes. Clouds of dust shoot into space, barely slowed by the weak gravitational pull of the comet's nucleus. As the dust jet propagates through the inner coma, astronomers on Earth photograph the sunlight reflected off the individual dust particles, hoping to understand more about the world's most famous comet.

Over the past year and a half the pages of ASTRONOMY have been filled with wide-field photographs of Comet Halley's ever-changing tails and with spacecraft images of the irregular, almost ghostly nucleus. However, narrow-field, high-resolution images of the coma taken by ground-based observers record aspects of the comet's fascinating dynamic behavior neither wide-field nor spacecraft images can show. Because of the time and effort required to bring out the subtle coma structure, these pictures are only now becoming available, yet they are destined to play a prominent role in studies of the long-term behavior of the nucleus of Comet Halley.

Laying the Foundation

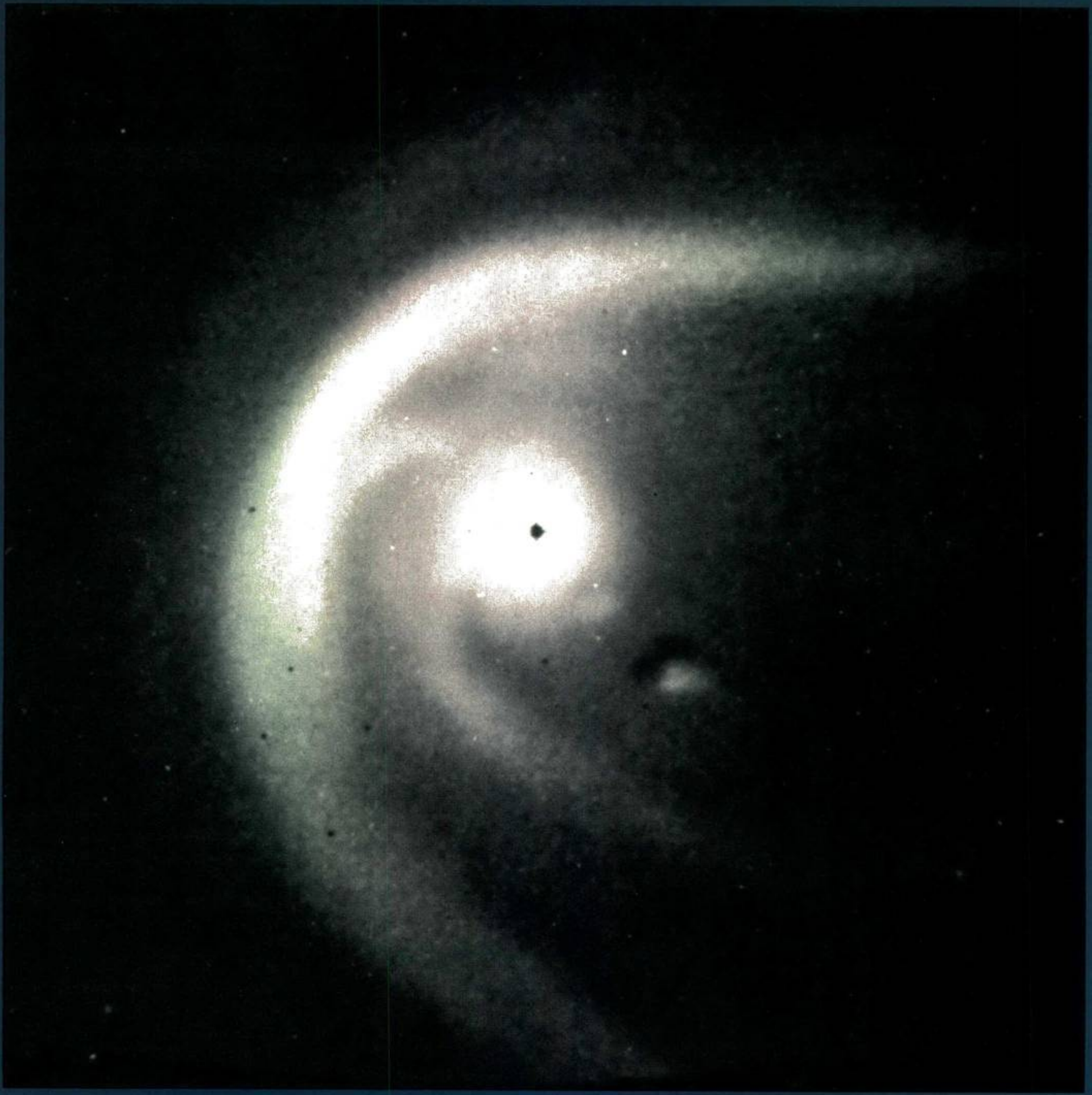
Discerning details near a comet's nucleus is difficult because dust and gas released from the nucleus tend to mask the comet's low-contrast inner regions. During the comet's 1683 appearance German astronomer Johannes Hevelius detected structure in the inner coma of Comet Halley while he was making some of the first telescopic observations of the comet. During the apparition of 1836 Friedrich Struve and John Herschel made numerous drawings of these near-nucleus features. Photographs taken in 1910 provided the first objective record of features in Halley's inner coma. Nearly one 76-year orbit later these photos were computer processed to bring out even more detail (see "Mining Old Silver" by Zdenek Sekanina and Stephen Larson, October 1985).

In 1986 astronomers needed a context for the observations made by the flotilla of spacecraft heading toward Halley. And only ground-based observations of Halley's changing behavior could provide this context for interpreting the spacecraft "snapshots." Partly for this reason the International Halley Watch (IHW) established the Near-Nucleus Studies Net as one of the eight major categories in the scientific study of Halley. Studying the structure — or morphology — of Halley's coma with high-resolution imaging did not fit easily into the categories of the other nets of the IHW, and unlike most other comets, Comet Halley was expected to have coma features. Spacecraft directly sampled Halley's near-nucleus environment, which also provided a unique opportunity for us to understand similar coma structure in the roughly 20 percent of comets that display discrete dust features.

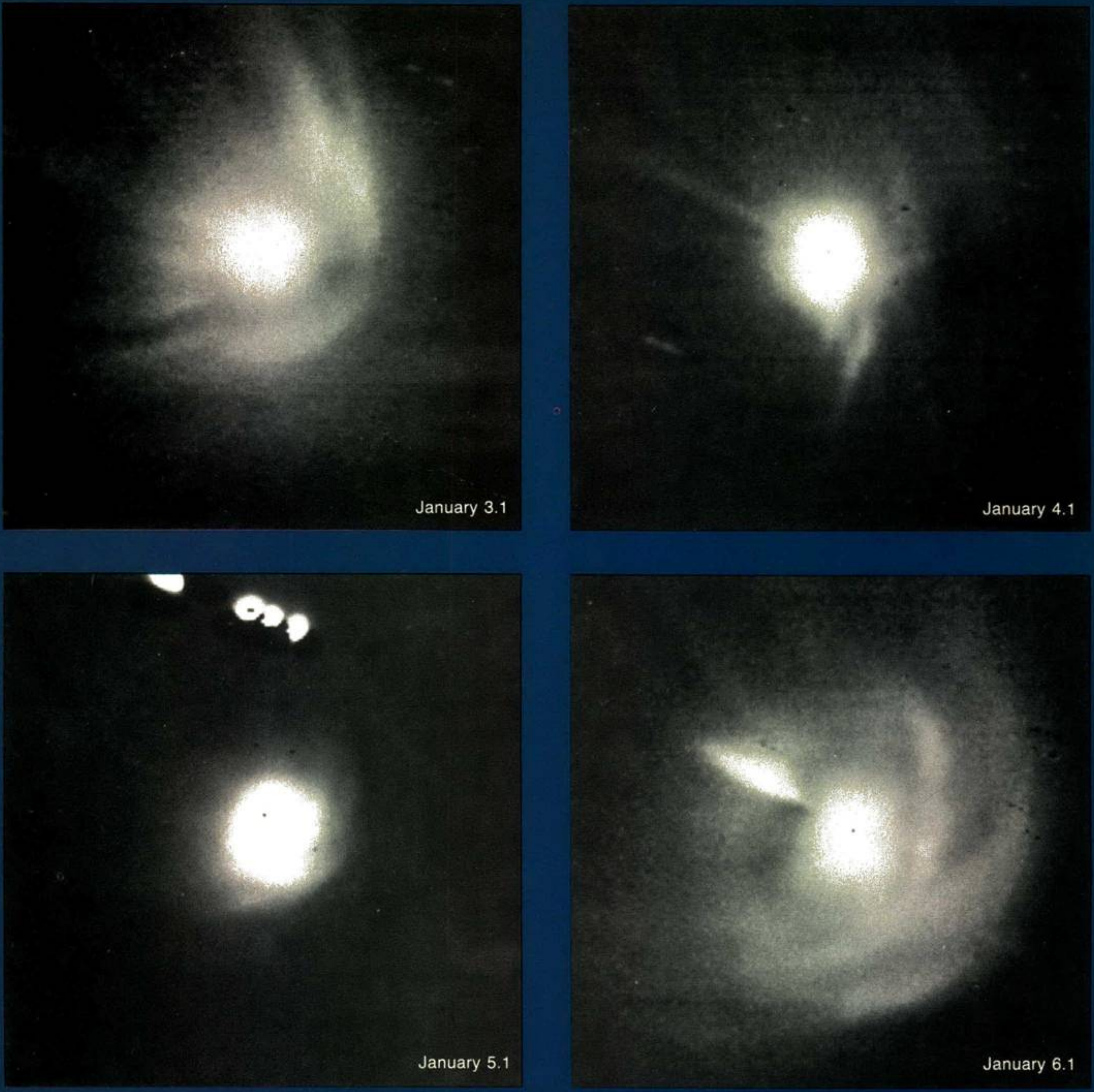
Modeling the Nucleus

When the Near-Nucleus Studies Net was formed, no one was sure what scientific results it would produce. Shortly afterwards, however, Zdenek Sekanina of the Jet Propulsion Laboratory and Stephen Larson of the Lunar and Planetary Laboratory demonstrated that most of the coma structure recorded in the 1910 pictures was a consequence of continuous daytime emission of dust from localized areas on the rotating nucleus. By adjusting the parameters that govern how dust particles are ejected into these "jets" in a computer model Sekanina developed and wrote, the two astronomers were able to match the computer output with the shapes of the coma features in the enhanced photographs. After many iterations of the computer model, a combination of nucleus rotation period, spin-axis orientation, and locations of jet sources emerged that was consistent with the 1910 observations and resulted in a map of jet sources on the nucleus.

Although the model reproduced the observed dust emissions for a wide range of viewing angles, the 1910 data were not extensive enough to establish either the long-term jet behavior or even the precise nucleus spin vector — a combination of the nucleus' rotation rate and the orientation of its axis of rota-



Above: High-resolution images of Comet Halley's coma reveal the presence of low-contrast features caused by dust ejected from the nucleus. On March 14, 1986, two "spirals" associated with the comet's dust jets extended from the central condensation. (All photos courtesy of the authors.)



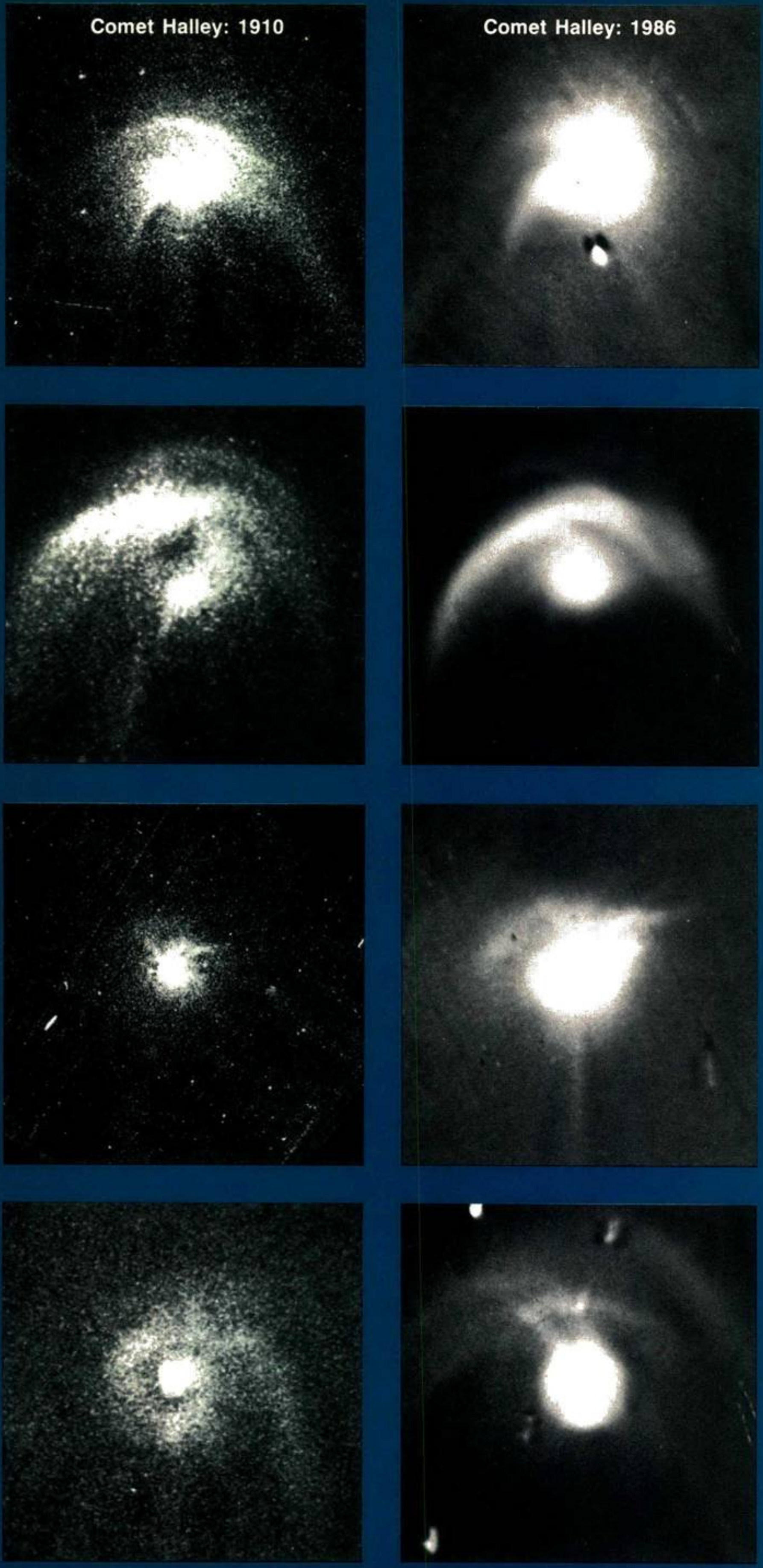
January 3.1

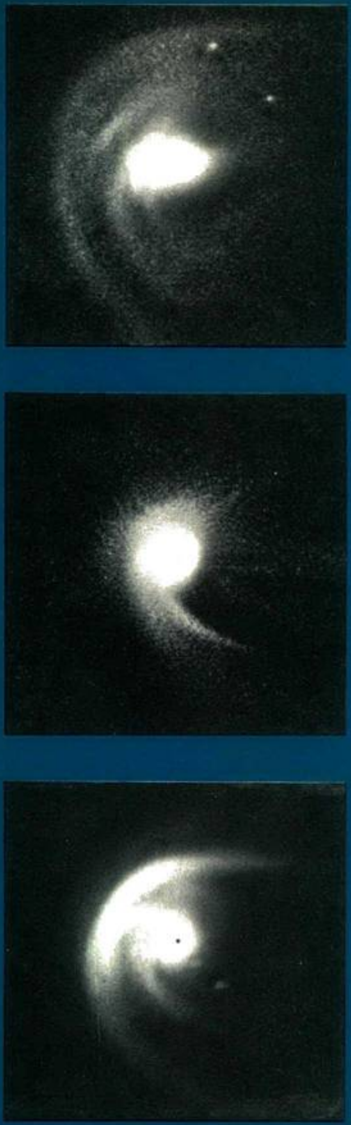
January 4.1

January 5.1

January 6.1

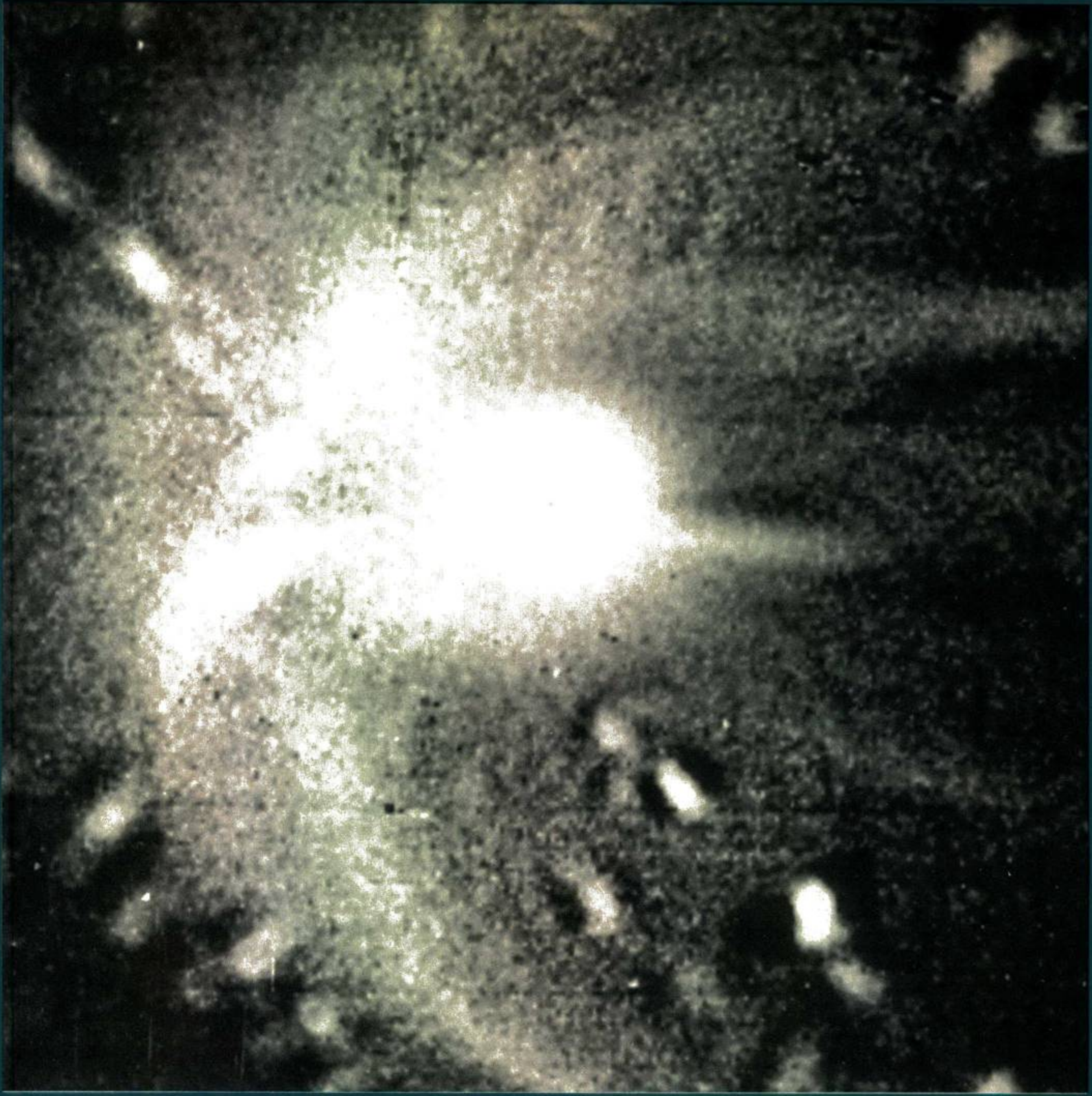
Above: Daily changes in the dust environment surrounding Halley are evident in this sequence of enhanced CCD images taken from January 3 to 6, 1986 (Universal Time). In all these images the Sun is to the lower right, and each frame is 150,000 kilometers square at the distance of the comet. Note the tailward-pointing jet in the January 4.1 image and the even stronger jet on January 6.1.





Above: Ground-based images confirm that each spacecraft encountering Halley experienced significantly different levels of comet activity. Halley was near peak activity during the *Vega 1* encounter (top, taken shortly after the flyby on March 7, 1986). Activity had dropped substantially by the time of the *Vega 2* encounter (middle, taken shortly after the flyby on March 10) and was at a moderate level during the *Giotto* flyby (bottom, March 14).

Left: A comparison of 1910 images (left column) with 1986 images (right column) show that Comet Halley exhibited similar coma structure at both apparitions. In fact, every type of feature seen in 1910 was seen again in 1986. These photos are oriented with the Sun at top; each frame represents an area 120,000 kilometers across. The 1910 photos were taken at the Lick and Mount Wilson observatories.



Above: Some of the CCD images of Halley, such as this one taken on March 12, 1986, show an incredible amount of coma structure. It will take several years to completely analyze these images, compare them with theoretical models, and from this arrive at a detailed understanding of Comet Halley's dust jets.

tion — of Comet Halley. Clearly a campaign to obtain the longest possible baseline of data on coma morphology during the 1985-86 apparition was needed to complement the high-resolution images from the Halley space probes. We even hoped to make some predictions about jet activity for the times of the spacecraft encounters by utilizing new techniques, modern communications, and over one hundred collaborating observers around the world.

To provide the space agencies with nearly real-time information on dust-jet activity near Halley's nucleus, the Inter-Agency Consultative Group, the consortium of four space agencies and the IHW that coordinated the spacecraft exploration of Halley, established a computer link between our base in Tucson and the European Space Operation Center in Darmstadt, West Germany. Later, after our study of the 1910 images, we realized we did not know enough about the detailed behavior or lifetimes of the jets to predict the presence of individual jets on a given rotation. We could only supply information on the general activity level of Halley's nucleus.

The 1986 Apparition

Although many observers were concerned because the comet was not well placed for viewing this time around, the Net obtained images of Comet Halley's changing coma morphology that were unprecedented in both quality and quantity. Advances in films and detectors since 1910 more than compensated for the inferior observing conditions during this apparition. Hypersensitized Kodak Technical Pan 2415 film and solid-state electronic charge-coupled device (CCD) detectors on moderate aperture telescopes outperformed the largest telescopes (such as the 1.5-meter Mount Wilson reflector) and the best photographic emulsions of 1910. The greater number of telescopes at all latitudes also added to the Net's success.

One of our contributions to this effort was designing and constructing two CCD systems tailored to high-resolution imaging studies. One would be used at Mauna Kea, Lowell, and Perth Observatories by a group under the direction of Michael A'Hearn of the University of Maryland and the other at Tucson and the Boyden Observatory of the University of the Orange Free State in South Africa by the two of us and Santiago Tapia. Because our funding was delayed, we had only four months to design, build, and check out the CCD cameras and optics modules in time for their first real test: the International Cometary Explorer encounter with Comet Giacobini-Zinner on September 11, 1985. (See "ICE: Mission to a Comet" by Richard Berry, December 1985.) Giacobini-Zinner served as a trial run for our CCD systems and provided us with an opportunity to work out any bugs before jet activity started on Comet Halley.

By mid-November 1985 dust jets were appearing regularly as Halley finally came close enough to the Sun. At this time the CCD systems were completely operational, and we started a nightly observing run with either the 0.5-meter telescope on Tumamoc Hill in Tucson or the 1.5-meter Catalina station telescope near Mount Bigelow, north of Tucson. We obtained images of Comet Halley on sixty-seven of the seventy-eight nights possible before the comet disappeared into the twilight glow on January 29, 1986.

Monitoring the daily changes in the dust-jet patterns, we noted that brightness outbursts observed with the *International Ultraviolet Explorer* satellite and by other astronomers occurred at the same times we saw bright jets. For the first time on January 3, 1986, we observed a curious tailward-pointing jet similar to one seen at least five times in 1910. Unlike the typical spiral jets, which originate in continuous emission and acquire their distinctive shape from the effects of the spinning comet nucleus, these straight tailward-pointing features often accompany spherical outbursts of material. As the pictures on page 92 show, an even stronger outburst just over two days later produced a more pronounced feature. At that time a 2.2-day rotation period for Halley's nucleus seemed to explain the jet shapes we observed, and the Japanese *Suisei* spacecraft's observations of the periodic nature of the comet's hydrogen emission supported this explanation.

When the comet reappeared after solar conjunction, we realized Halley had changed. Apparently the solar heating around perihelion liberated greater quantities of dust from the nucleus, and Halley became a dustier comet with stronger dust jets. From the time we started observing at Boyden Observatory in late February until just before the *Vega 1* spacecraft encountered Halley on March 6, the two-day periodicity in jet activity was quite pronounced. We were able to predict that Halley would be very active during the *Vega 1* encounter, while during the *Vega 2* encounter three days later the comet would be less active. This latter prediction came as a relief to Soviet researchers, who were concerned for *Vega 2*'s health after the buffeting *Vega 1* received. *Giotto* encountered moderate activity during its close approach.

How "Normal" Was Halley in 1986?

Perhaps our most important contribution to the scientific study of Halley was determining that the comet was essentially "normal" during its 1986 apparition. We found that the computer-enhanced images taken in 1986 showed all of the types of coma features seen in the 1910 images and, in fact, some of the features were virtually identical at the two apparitions. Because of this apparent lack of appreciable change, the same processes most likely have been taking place in the comet for many revolutions around the Sun.

Although the tailward-pointing jets seen during this apparition occurred over the same range of comet-Sun distances in the 1910 apparition, we still do not have a detailed understanding of the process that produces these jets. The qualitative similarities have to be backed up with quantitative modeling — something that will probably take a few years to accomplish.

Before much of that modeling is done, however, an apparent conflict must be resolved. Robert Millis and David Schleicher of Lowell Observatory found that Halley has a double-peaked light curve with a 7.4-day period. This 7.4-day period may represent a component of rotation in addition to the 2.2-day period previously found, but in any case the finding will force a re-evaluation of the nucleus spin vector and could affect the modeling of the dust jets. Our near-nucleus data will be instrumental in resolving this issue.

The work of the Near-Nucleus Studies Net has turned out to be as fruitful as we had hoped it would be. By carefully recording where and when the dust jets occurred, we should be able to determine the precise motions of the jet features and compare them with models. Clearly we are in for several years of work before we can discuss the results of this research — the lifetimes and evolution of dust jet sources on Comet Halley's nucleus. But just as clearly this new knowledge will be a significant advance in the study of cometary behavior.

Stephen Larson is a planetary astronomer at the University of Arizona's Lunar and Planetary Laboratory and a near-nucleus discipline specialist for the International Halley Watch. David H. Levy is also affiliated with the Lunar and Planetary Laboratory and the discoverer of two comets.

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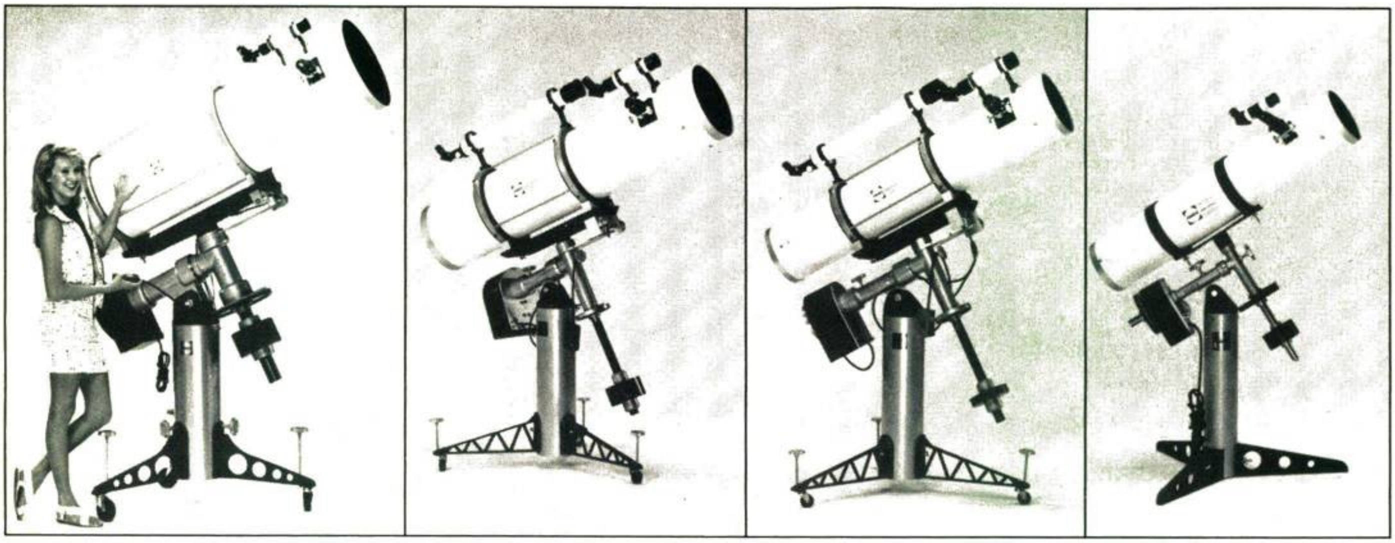

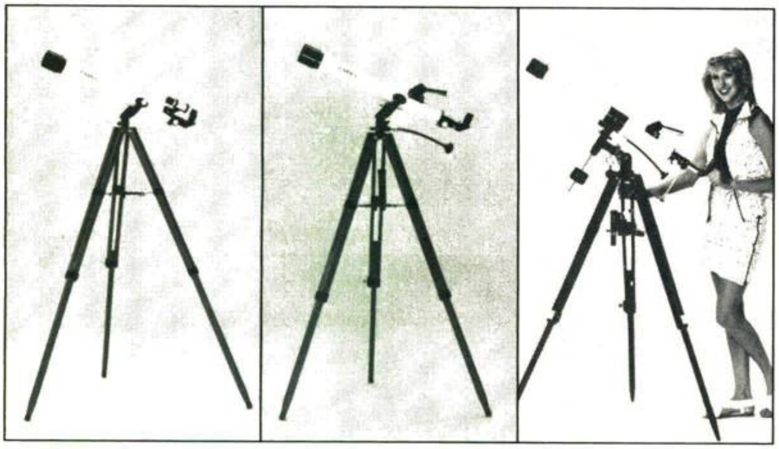

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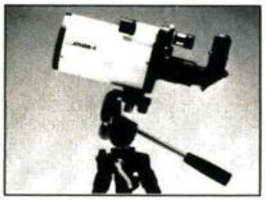

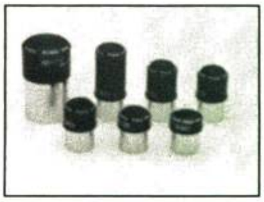

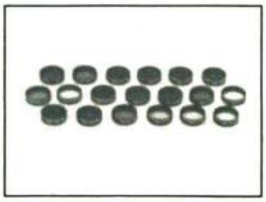

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Exploring the Summer Milky Way

By Robert Reeves

As magnificent as the summer Milky Way is to the human eye, the eye of the camera sees more. To the human eye the star clouds of the Milky Way appear detailed, but as soon as you try to hold specific details, they seem to vanish.

Not so with the camera. Once the details are captured on film, you can explore the star clouds and dark rifts of the Milky Way in all their glory — and you can do it on a cold, cloudy night in the middle of winter. You can also share your "take" with friends or the readers of ASTRONOMY!

The Milky Way is really quite easy to photograph. You need a camera with a sharp, fast lens: the ordinary 50mm lens mounted on your 35mm camera is ideal for this purpose. The f/stop should be f/3.5 or faster, but superfast lenses aren't always useful. I normally stop my f/1.4 lenses to f/2.8 for crisper images. Your camera must also be capable of time exposures. Consult the camera manual before you begin shooting long exposures, especially if your camera's shutter is battery-powered.

To keep your camera accurately pointed at the same place in the sky during exposures that may run up to thirty minutes, you will need an equatorially mounted telescope or a tracking platform. If you mount your camera piggyback on the telescope, be sure to use a sturdy bracket or clamp. If you don't have an equatorial mount, you'll find a tracking platform is a lot less expensive than a telescope and every bit as good for shooting "piggyback" exposures.

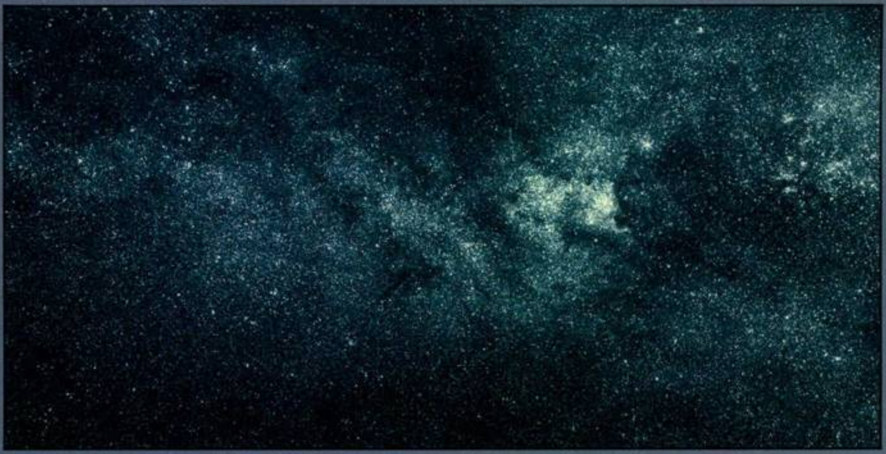
Although you might start taking Milky Way pictures from your backyard, there's nothing like spending time looking at the Milky Way to sensitize you to light pollution. Unless you live at least ten miles from the nearest small town and one hundred miles from the nearest big city, you'll soon be wishing for darker skies.

I found truly dark skies at the Texas Star Party, held annually in the Davis Mountains of western Texas, in 1986. The sky there is certainly worth the trip. Few other places in the United States are so free of light pollution, dust, and humidity. In the hour just before dawn, when the summer Milky Way is at its highest, the star clouds of Sagittarius and Scorpius shine so brightly that I have seen them cast shadows.

Under these conditions the eye of the camera will capture the dark outline of the Great Rift and the tiniest details in the structure of the glowing star clouds. Each frame is such a stunning portrait of a bit of our Galaxy that I find myself studying these photos for hours. Stopped down to f/2.8, most 50mm lenses are so sharp you could hardly ask for more.

Beautiful as the single frames are, you can really wow yourself by assembling a dozen or so exposures into a panorama. Lo and behold, the bright star clouds and dark rifts form huge structures that span half the sky — and you've shot them on 35mm film!

To take the panoramic photograph on the following pages, I made a bracket to hold two cameras piggyback on my equatorially mounted telescope. Using two cameras, I was able to take all fourteen frames in one night. I used matched 50mm f/1.4 Nikon lenses, stopped down to f/2.8 for sharpness, to record a 30° by 70° strip of the sky during each 30-minute exposure. I didn't do anything fancy to point the cameras: I simply aligned each pair of photographs by sighting through the view finder. You could do just as well with a single camera, but then shooting the frames would take twice as long. There's no reason why taking the pictures in two or three sessions on different nights would cause any problem, provided the nights were equally clear and dark.

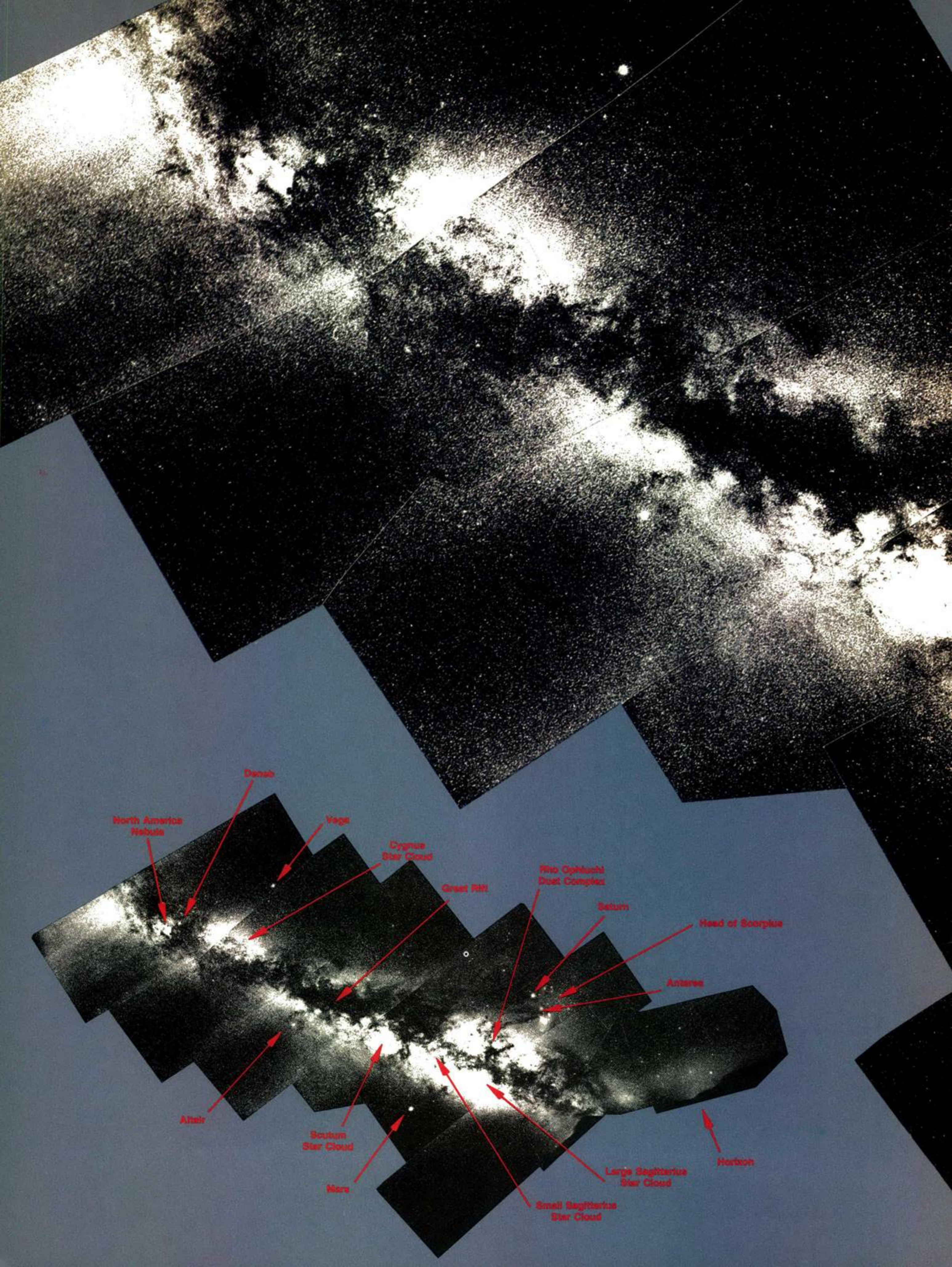


Single frames can show a wealth of Milky Way detail. Photo by Martin Germano.

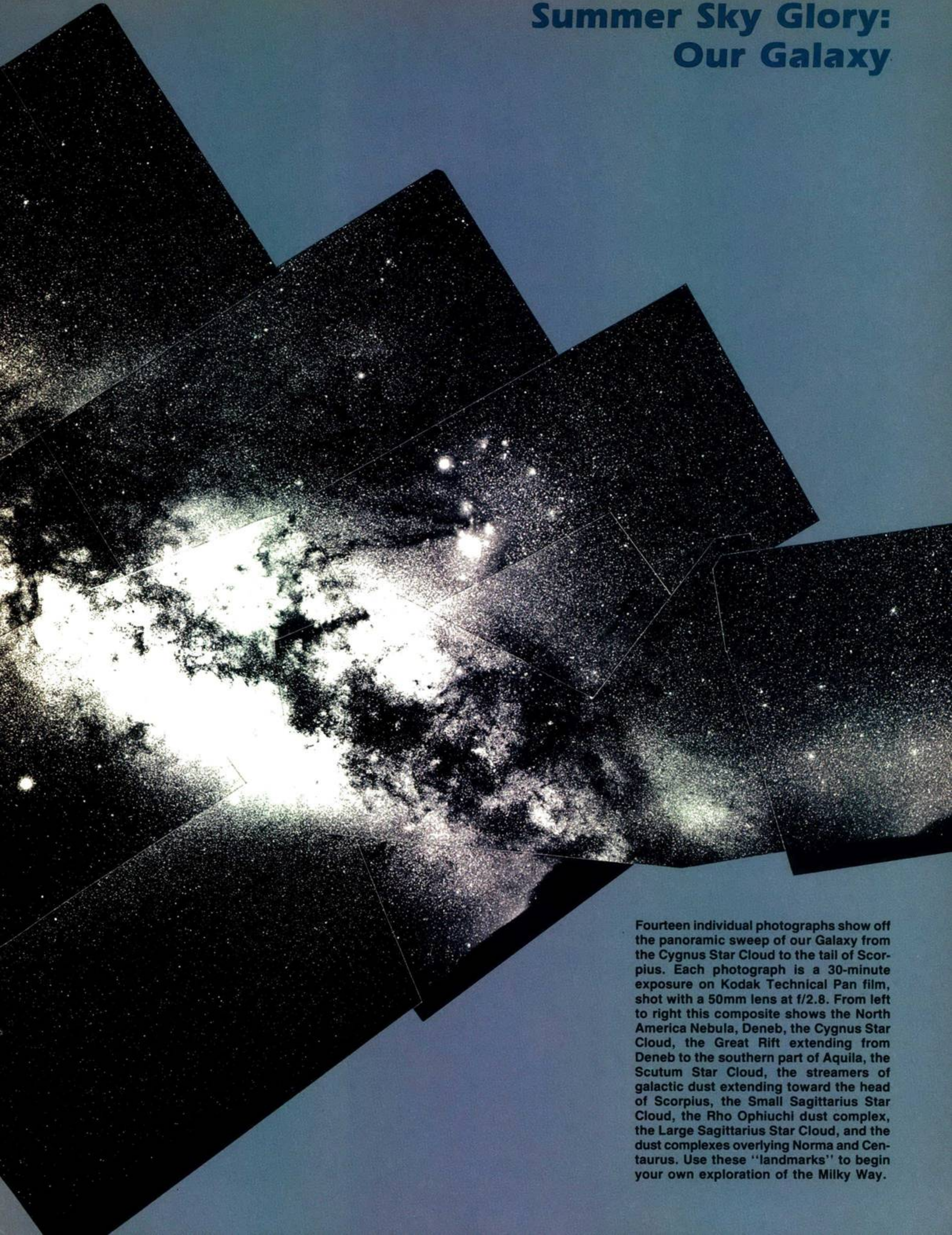
I shot my composite on hypersensitized Kodak 2415 Technical Pan film. All of the exposures were 30 minutes. I made prints on Kodak Kodabrome II RC paper, glossy, grade 5. The panoramic shot is assembled with transparent tape.

I used Tech Pan film because I wanted the high contrast and fine grain this film offers. You might want to try shooting your own panorama in color. Fair warning: color is considerably more difficult to use than black and white because you have to get matching background color in adjacent frames, which isn't easy.

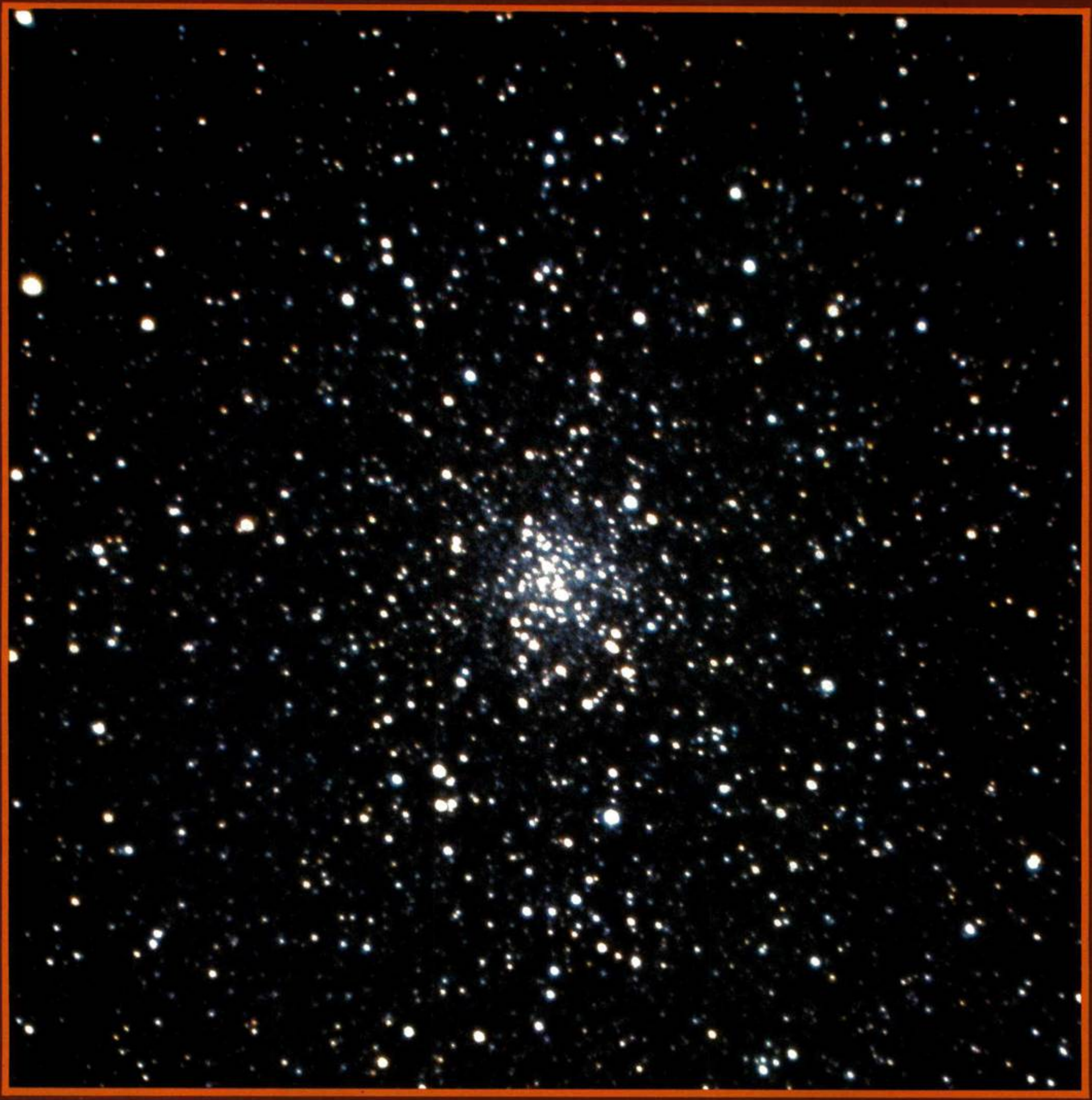
The beauty of piggyback Milky Way photography is that anyone with a suitable camera and enough gumption to get out and do it can achieve results like this. Try exploring our Galaxy with your camera. You'll be amazed at how much beauty you'll uncover.

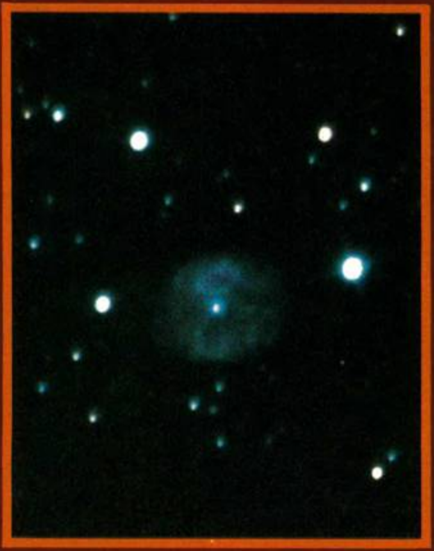

Deneb
North America Nebula
Vega
Cygnus Star Cloud
Great Rift
Rho Ophiuchi Dust Complex
Saturn
Head of Scorpius
Antares
Altair
Scutum Star Cloud
Nova
Small Sagittarius Star Cloud
Large Sagittarius Star Cloud
Horizon

Summer Sky Glory: Our Galaxy



Fourteen individual photographs show off the panoramic sweep of our Galaxy from the Cygnus Star Cloud to the tail of Scorpius. Each photograph is a 30-minute exposure on Kodak Technical Pan film, shot with a 50mm lens at f/2.8. From left to right this composite shows the North America Nebula, Deneb, the Cygnus Star Cloud, the Great Rift extending from Deneb to the southern part of Aquila, the Scutum Star Cloud, the streamers of galactic dust extending toward the head of Scorpius, the Small Sagittarius Star Cloud, the Rho Ophiuchi dust complex, the Large Sagittarius Star Cloud, and the dust complexes overlying Norma and Centaurus. Use these "landmarks" to begin your own exploration of the Milky Way.





Above: Globular cluster M-71 in Sagitta is so easy to resolve into stars that for years many observers believed it was a rich open cluster. Photo by Bill Iburg.

Far left: Because planetary nebula NGC-6905 in Sagitta appears as a fuzzy ''star'' in small telescopes, a 6- or 8-inch telescope is required for a good view. Photo by Jack B. Marling.

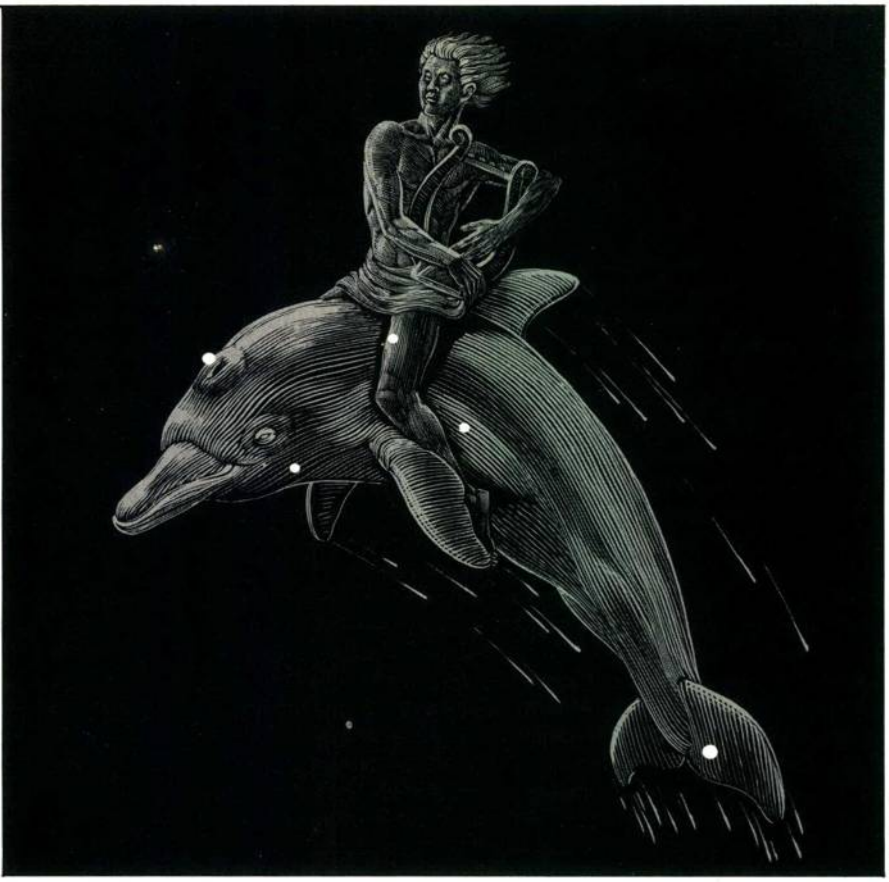
Left: One of the most distant globulars visible in backyard telescopes is Delphinus' NGC-7006, a 3′-diameter ball of gray light. Photo by Jack Newton.

Delphinus

Del
Delphini

Sagitta

Sge
Sagittae



Keith Ward

Delphinus the Dolphin and **Sagitta** the Arrow are both small, bright groups of stars lying near the plane of the Milky Way. Delphinus is a kite-shaped constellation holding five 4th-magnitude stars and a sprinkling of globular clusters and planetary nebulae. Sagitta contains a similar blend of globulars and planetaries and is one of the few constellations that actually looks like what it represents.

The brightest deep-sky object in the area is globular cluster **M-71** (NGC-6838), which is bright enough to be visible in any telescope or pair of binoculars. M-71 is easy to find because it lies midway between the 4th-magnitude stars Gamma (γ) and Delta (δ) Sagittae. To position M-71 in your telescope, move 2° southwest from Gamma Sagittae: you should see a small, fuzzy glow of light from the cluster.

M-71 is thought to have been discovered in 1775 by Johann G. Koehler in Dresden, Germany. However, there is evidence suggesting Phillippe de Cheseaux observed the cluster as early as 1746. In June 1780 the cluster was rediscovered by Charles Messier's colleague Pierre Mechain, which prompted Messier to search for the cluster. Messier's notes describe his seventy-first listing as "very faint . . . it contains no star . . . the least light extinguishes it."

The view through modern backyard telescopes is considerably better. A 3-inch refractor at low power shows a bright knot of light surrounded by a rich field of bright stars. Six-inch telescopes show M-71 as a hazy glow 5′ across, peppered by dozens of 11th- and 12th-magnitude stars. The cluster's total magnitude is 8.3, which makes it appear very bright in large backyard scopes. A 12-inch scope resolves over one hundred stars across a 7′-diameter disk, which demonstrates that M-71 is one of the "loosest" bright globular clusters. The cluster also lacks the typically strong central condensation of normal globular clusters.

For information on naked-eye sky viewing, including planets, constellations, and mythology, see **Eye on the Sky**.

M-71 is so easily resolved that for many years astronomers argued over whether it was a loose globular cluster or an extremely rich open cluster. After years of debate with good evidence supporting each side, most astronomers now believe M-71 is an unusual globular cluster.

Less than one degree southwest of M-71 is the sparse open cluster **Harvard 20**. Measuring 7′ across and glowing at magnitude 7.7, H20 is a fine cluster in binoculars and small scopes at low power. Such instruments show the group as a collection of fifteen stars, the brightest shining at magnitude 10. Large telescopes at low powers improve the view of H20 and show myriad faint field stars in and around the cluster. High-power views of H20 are unimpressive because the sprinkling of stars ceases to appear like a cluster and takes on the look of a typical Milky Way starfield.

Sagitta contains three fine planetary nebulae for small telescopes. Lying 2.5° east of the 6th-magnitude optical double 15 Sagittae is the faint planetary **NGC-6879**. Finding NGC-6879 is fairly easy because NGC-6879 lies along an east-west row of four 7th-magnitude stars, between and slightly north of the two easternmost stars. This object has a photographic magnitude of 13.0 and a diameter of 5″, which mean you'll have to use relatively high power and observe during a period of good seeing. With an 8-inch scope at 200x, NGC-6879 appears like a tiny out-of-focus star with a distinctly bluish cast. NGC-6879's central star glows dimly at magnitude 15, which makes it exceedingly difficult to see.

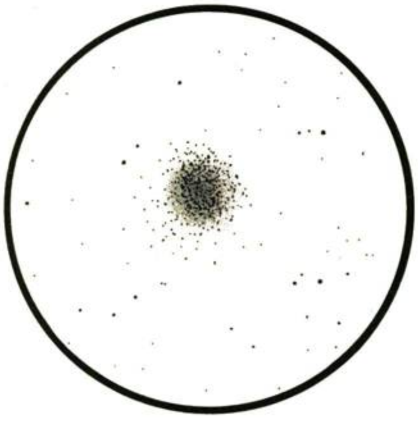
Three degrees east and slightly south of NGC-6879 is the bright, nearly stellar planetary **IC 4997**. This object shines at photographic magnitude 11.6 but measures only 2″ across. Successfully distinguishing IC 4997 from the stellar backdrop requires a long-focus telescope and very steady seeing. An 8-inch f/10 SCT at 300x reveals the planetary as a disk. The central star in IC 4997 is a variable that usually hovers at around 13th magnitude. The surrounding nebulosity may make this star somewhat difficult to see — especially if seeing is poor — but the star should be faintly visible in a 10-inch telescope.

Now move your telescope 3.5° north and 0.5° east from NGC-6879, and you'll encounter another small planetary, **NGC-6886**. NGC-6886 shines at photographic magnitude 12.2 and spans a mere 4″, so identifying NGC-6886 also requires a large, long-focus telescope and steady seeing. Its central star dimly glows at magnitude 15.7, which makes it very difficult to observe.

Considering its size, Sagitta contains a disproportionately high number of odd stars. **WZ Sagittae**, an unusual recurring

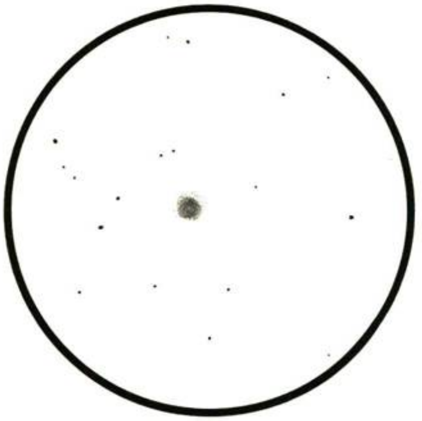
M-71

8-inch
f/10 SCT
50x



NGC-7006

17.5-inch
f/4.5 reflector
71x



Sketches by David J. Eicher

nova, can be found 1° northwest of NGC-6879, halfway between the row of 7th-magnitude stars around NGC-6879 and an inverted V-shaped asterism of 7th- and 8th-magnitude stars to the northwest. Three major outbursts of WZ Sagittae have occurred: in 1913, 1946, and 1978. This star normally stays around 15th magnitude, but during an outburst it typically rises to 7th magnitude. Careful observations of the previous three outbursts suggest the outbursts may result from interaction between two stars in the WZ Sagittae system, one of which is a white dwarf. Presumably another outburst can be expected sometime near 2010.

Just 25′ northwest of the planetary NGC-6886 is the unusual variable star **FG Sagittae**, which was discovered in 1943 by the German astronomer C. Hoffmeister. Images of FG Sagittae on plates made at Heidelberg Observatory and Harvard Observatory show that the star has gradually increased in brightness over the last seventy-five years. FG Sagittae shone at magnitude 13.7 in 1890, 10.3 in 1959, and 9.5 in 1967. Since the early 1970s the star has stopped its general brightening but began varying by 0.5 magnitude over a period of about two months. A tenuous nebula surrounds this star, but it is too faint to be visible in backyard telescopes.

In the extreme northeastern part of Sagitta is the erratic variable star **V Sagittae**. This star varies irregularly between magnitudes 9.5 and 13.9 with three overlapping periods of variability. Astronomers believe the unusual variability of the V Sagittae system indicates the star may have once been a nova or may soon become one.

The two brightest objects in Delphinus are double stars, each representing one star in the constellation's kite-shaped asterism. **Beta (β) Delphini** is composed of magnitude 4.0 and 4.9 stars separated by 2.5″. Both stars are white and should be visible with a 3-inch scope at high power. **Gamma (γ) Delphini** consists of magnitude 4.5 and 5.5 stars separated by the relatively wide distance of 9.6″. Each of Gamma's stars has a distinctly yellowish cast.

Three degrees north of the distinctive kite-shaped asterism is **HR Delphini**, otherwise known as Nova Delphini 1967. Discovered at magnitude 5.6 by English amateur astronomer George Alcock on July 8, 1967, the star stayed at 5th magnitude until September 1967, when it rose to 4th magnitude. After fading slightly, the star rose to magnitude 3.5 in December of that year and then faded to magnitude 11.5 by 1975. The star has since faded to magnitude 12.4 and is visible as a rather ordinary Milky Way star.

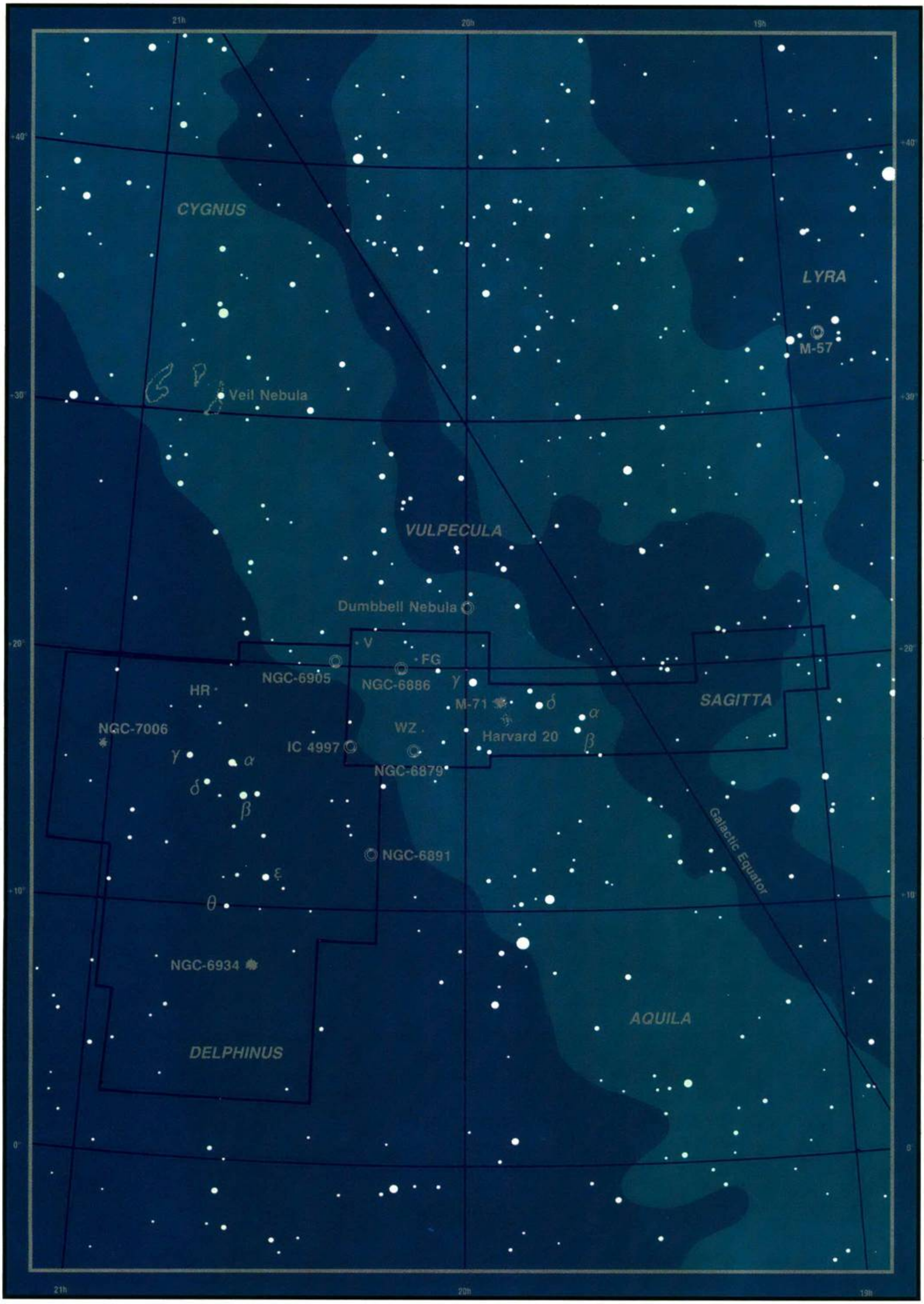
Delphinus contains two planetary nebulae well-suited to small telescopes. **NGC-6891** lies on the western border of Delphinus, some 1.5° southwest of a distinct pair of 6th-magnitude stars. With a photographic magnitude of 11.7 and a diameter of 12″, this nebula is easily visible as a nebular disk with a 4-inch scope. An 8-inch scope shows it as a small bluish green patch of light with a 12th-magnitude central star embedded within. In the northern part of Delphinus lies **NGC-6905**, a photographic magnitude 11.9 object with a diameter of 46″. This object appears as a beautiful ring-shaped nebula with a faint central star in an 8-inch scope. Larger instruments show NGC-6905 as one of the finest planetaries in the summer sky.

NGC-6934 is a 9th-magnitude globular cluster lying in southern Delphinus about 1° northwest of a pair of 6th- and 7th-magnitude stars. Backyard telescopes show this object as a 5′-diameter fuzzy disk of nebulosity with a bright core. Ten degrees away in the northeast part of Delphinus lies the globular cluster **NGC-7006**. Glowing dimly at magnitude 10.6 and spanning only 2.8′, NGC-7006 is certainly not a terrifically impressive globular cluster for small scopes. However, it is the most distant globular visible from the backyard, lying an immense 37 kiloparsecs away.

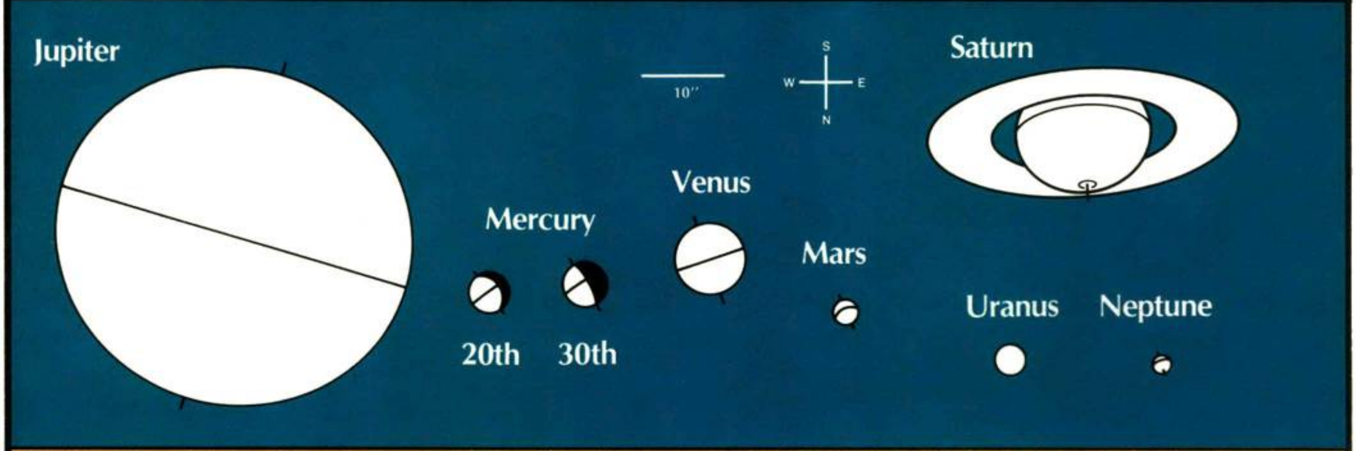
Object	M#	Type	R.A. (2000)	Dec.	Mag.	Size/Sep./Per.	N★	Mag.★
Harvard 20		⊙	19h 53.1m	+18°20′	7.7	7′	15	9.8
NGC-6838	M-71	●	19h 53.8m	+18°47′	8.3	7.2′		
WZ Sge		N	20h 07.6m	+17°42′	7.0↔15.5	32.6 yr?		
NGC-6879		■	20h 10.5m	+16°55′	13.0_P	5″		15_P
FG Sge		IV	20h 11.9m	+20°20′	9.5↔13.7	irr.		
NGC-6886		■	20h 12.7m	+19°59′	12.2_P	4″		15.7
NGC-6891		■	20h 15.2m	+12°42′	11.7_P	12″		12.4
IC 4997		■	20h 20.2m	+16°45′	11.6_P	2″		13v?
V Sge		N	20h 20.3m	+21°06′	9.5↔13.9	—		
NGC-6905		■	20h 22.4m	+20°07′	11.9_P	46″		13.51_B
NGC-6934		●	20h 34.2m	+7°24′	8.9	5.9′		
Beta (β) Del		★²	20h 37.5m	+14°36′	4.0,4.9	2.5″		
HR Del		N	20h 42.3m	+19°10′	3.7↔12.4	—		
Gamma (γ) Del		★²	20h 46.7m	+16°07′	4.5,5.5	9.6″		
NGC-7006		●	21h 01.5m	+16°11′	10.6	2.8′		

★²	*Double Star*
N	*Nova*
⊙	*Open Star Cluster*
●	*Globular Star Cluster*
■	*Planetary Nebula*
IV	*Irregular Variable Star*

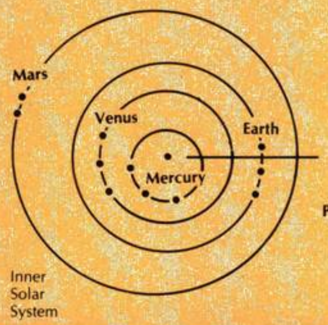
N★ = number of stars, Mag.★ = magnitude range of cluster or magnitude of central star, (...) indicates many fainter.

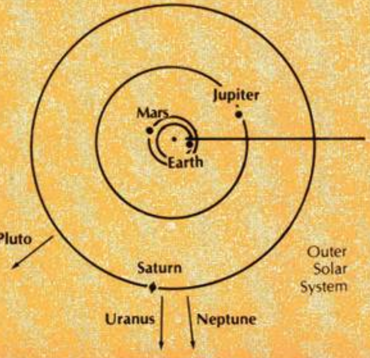

21h
20h
19h
+40°
+30°
+20°
+10°
0°
CYGNUS
LYRA
M-57
Veil Nebula
VULPECULA
Dumbbell Nebula
V
FG
NGC-6905
NGC-6886
γ
HR
M-71
δ
α
NGC-7006
WZ
Harvard 20
β
SAGITTA
IC 4997
NGC-6879
γ
α
δ
β
NGC-6891
ε
Galactic Equator
θ
NGC-6934
AQUILA
DELPHINUS
21h
20h
19h

Planetary Data September 1987


Jupiter
10″
S
W
E
N
Saturn
Venus
Mercury
20th
30th
Mars
Uranus
Neptune

						Distance (AU) from:		Longitude:			
		Date	Mag.	Angular Size	% Illum.	Earth	Sun	Heliocentric	Ecliptic	R.A. (2000.0)	Dec.
Sun		1	−26.7	31.8′	—	1.009	—	—	158°02.8′	10h 39.5m	8°29.5′
		15	−26.7	31.9′	—	1.006	—	—	171°37.9′	11h 29.9m	3°15.2′
		30	−26.7	32.0′	—	1.002	—	—	186°18.5′	12h 23.8m	−2°34.3′
Mercury	☿	1	−0.8	5.0″	94%	1.356	0.412	196°23.1′	169°00.5′	11h 21.5m	5°22.4′
		15	−0.2	5.4″	83%	1.254	0.461	239°35.1′	191°40.3′	12h 42.3m	−5°06.2′
		30	0.0	6.3″	67%	1.064	0.456	281°17.8′	211°30.1′	13h 54.6m	−14°18.3′
Venus	♀	1	−3.9	9.7″	100%	1.726	0.719	163°48.9′	160°37.1′	10h 50.6m	8°54.0′
		15	−3.9	9.8″	100%	1.712	0.721	186°30.1′	178°00.0′	11h 54.8m	2°02.0′
		30	−3.9	9.9″	99%	1.686	0.722	210°40.8′	196°39.4′	13h 03.0m	−5°34.7′
Mars	♂	10	1.8	3.5″	100%	2.666	1.666	158°26.7′	161°45.2′	10h 54.3m	8°10.3′
		20	1.8	3.5″	100%	2.651	1.665	162°48.9′	168°08.1′	11h 18.0m	5°50.7′
Jupiter	♃	15	−2.8	47.9″	100%	4.113	4.954	21°35.8′	28°45.4′	1h 49.2m	9°36.2′
Saturn	♄	15	0.5	16.4″	100%	10.099	10.034	260°49.5′	255°17.7′	16h 56.7m	−21°18.1′
Uranus	⛢	15	5.6	3.7″	100%	19.183	19.230	265°47.6′	263°06.8′	17h 23.3m	−23°24.9′
Neptune	♆	15	7.9	2.3″	100%	29.980	30.232	277°05.1′	275°30.0′	18h 23.4m	−22°19.2′
Pluto	♇	15	13.8	0.1″	100%	30.336	29.682	219°16.8′	218°20.0′	14h 43.8m	0°47.1′

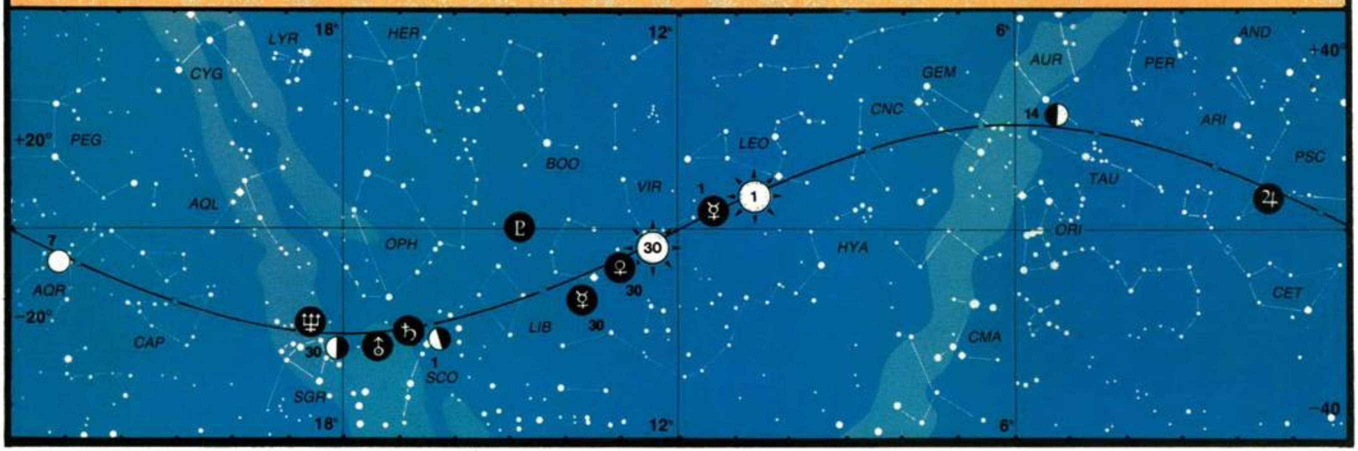

Mars
Venus
Earth
Mercury
Inner Solar System


Jupiter
Mars
Earth
Pluto
Saturn
Outer Solar System
Uranus
Neptune

Moon Data

First Quarter	Sept. 1 at 3h48m
Full Moon	Sept. 7 at 18h13m
Last Quarter	Sept. 14 at 23h44m
New Moon	Sept. 23 at 3h08m
First Quarter	Sept. 30 at 10h39m
Full Moon	Oct. 7 at 4h12m

Perigee: Sept. 6 at 2h43m UT. . 360,926 km
Apogee: Sept. 18 at 3h05m. . . . 405,189 km


LYR
18h
HER
12h
6h
AUR
AND
CYG
GEM
PER
+40°
CNC
14
ARI
+20°
PEG
LEO
BOO
PSC
TAU
VIR
1
1
AQL
7
ORI
HYA
OPH
30
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LIB
30
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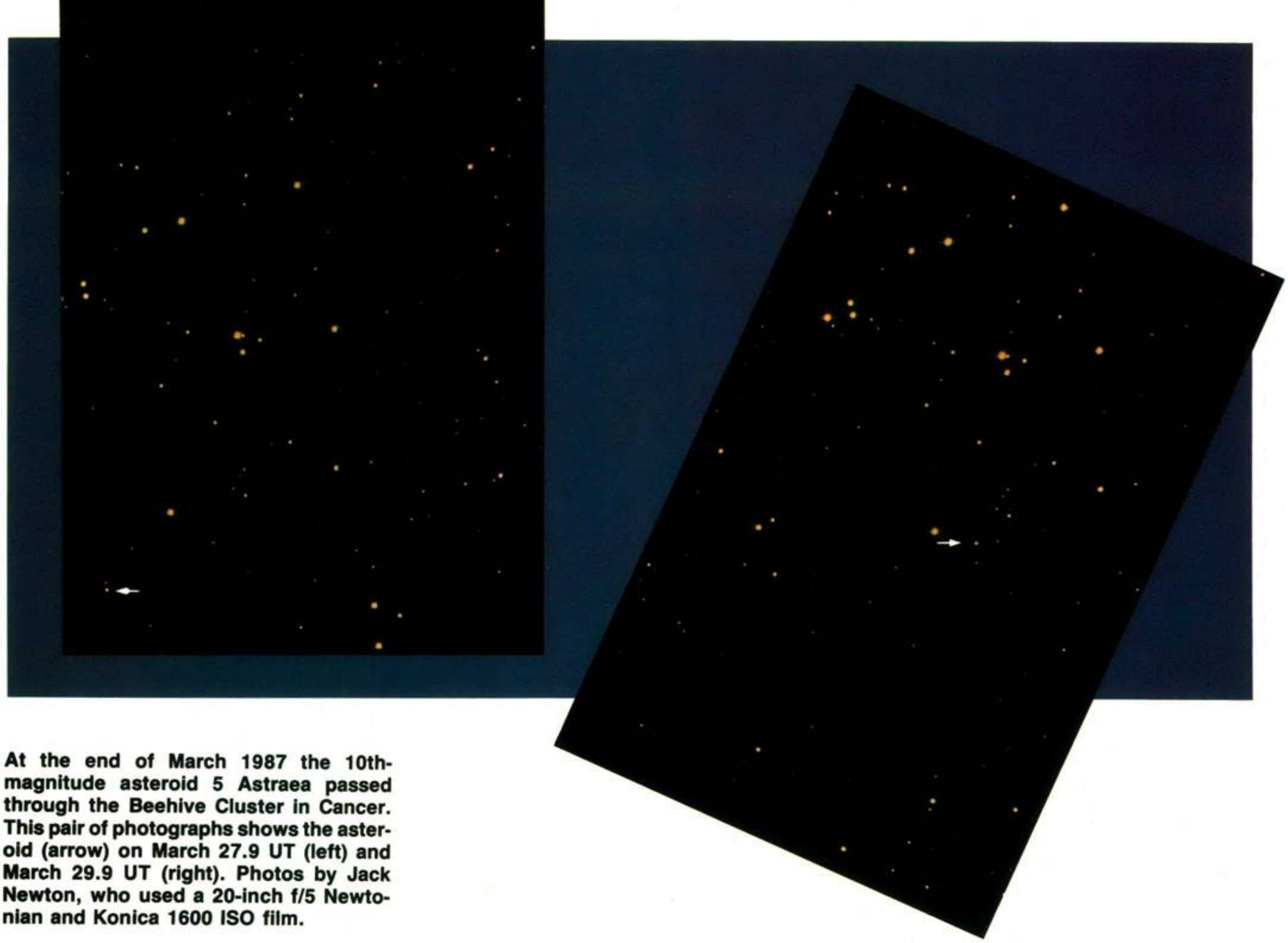
30
CMA
CAP
1
SCO
SGR
18h
12h
6h
−40



At the end of March 1987 the 10th-magnitude asteroid 5 Astraea passed through the Beehive Cluster in Cancer. This pair of photographs shows the asteroid (arrow) on March 27.9 UT (left) and March 29.9 UT (right). Photos by Jack Newton, who used a 20-inch f/5 Newtonian and Konica 1600 ISO film.

Mercury

Mercury's appearance in the evening sky this month and next will be the year's poorest. The ecliptic, along which Mercury is traveling, lies at such a shallow angle to the sunset horizon that the planet sets soon after the Sun does. Peak elevation comes late in September and reaches a scant 1° (forty-five minutes after sunset). The planet's greatest elongation is on October 4.

In the evening twilight of the 22nd, −0.1-magnitude Mercury will lie about half a degree to the right of 1.0-magnitude Spica. Mercury's apparent diameter will be 5.7″ (its disk is 75 percent illuminated), but both Mercury and Spica will lie very low in the west-southwest, so the bright evening twilight will make locating and viewing them difficult.

This apparition is unfavorable, but the one that closes out the year in November and December will be much better: Mercury will climb to about 10° in the southeastern sky before sunrise.

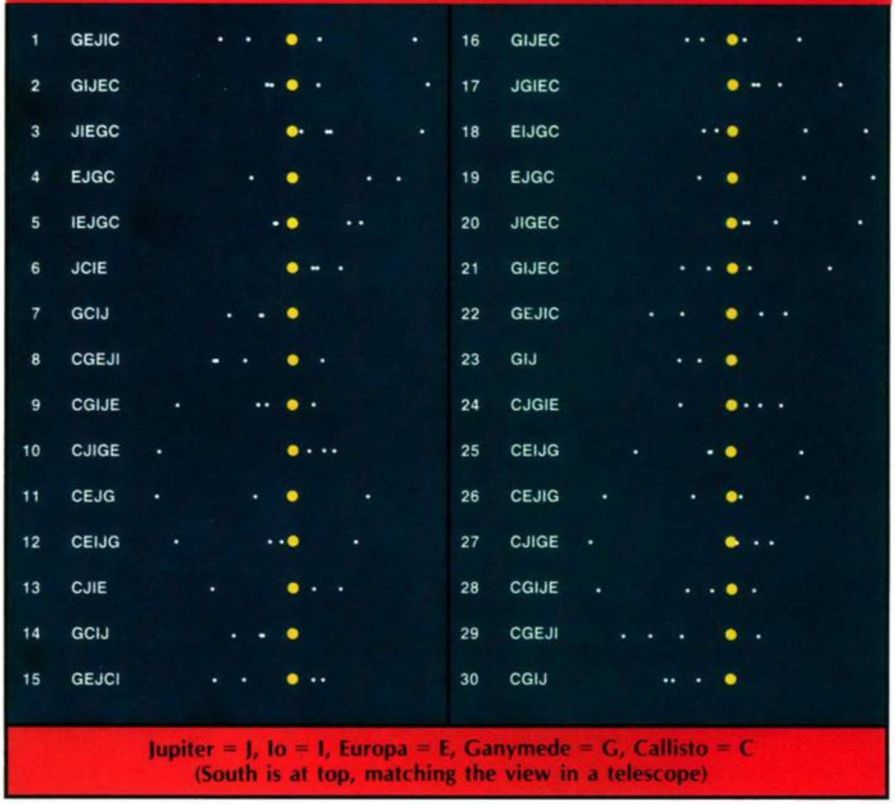
Venus

Venus is lost in the solar glare this month, having passed superior conjunction late in August. We won't catch sight of Venus in the evening sky until October.

Moon

On September 23, about ten hours before the moment of equinox, the Moon will cross the face of the Sun for viewers in eastern Siberia, China, and the west-

Satellites of Jupiter 5h00m UT



Stars abound in the Sagittarius region of the Milky Way surrounding the Lagoon and Trifid nebulae. This image was made with a 8-inch f/1.5 Schmidt camera, Ektachrome 200 film, and a 10-minute exposure. Photo by Mike Mayerchak.

ern Pacific Ocean. This eclipse is "annular," which means the Moon's apparent size isn't large enough to cover the entire solar disk. (The name derives from the ring or *annulus* of Sun that surrounds the Moon at maximum eclipse.) No solar corona will be visible.

A partial eclipse will occur over an area that includes most of eastern Asia, parts of Indonesia, the northeastern half of Australia, most of New Zealand, and much of the western Pacific. From Hawaii a very shallow nick will be taken out of the Sun's disk just before local sunset on the 22nd, but you'll need a telescope and safe observing techniques (eyepiece projection or a full-aperture solar filter) to see it.

Mars

In conjunction with the Sun on August 25, Mars lies too close to the Sun to be seen through most of September. In the last few days of the month, however, sharp-eyed observers may catch sight of Mars low in the east just before sunrise. Unfortunately, the unsettled seeing near the horizon will prevent good telescopic views.

Minor Planets

1 Ceres (magnitude 8.1) is moving eastward in southern Ophiuchus and eastern Sagittarius. Its positions:

1st: 17h 29m 24s, −28° 01.4′
10th: 17h 35m 05s, −28° 11.6′
20th: 17h 43m 19s, −28° 21.4′
30th: 17h 53m 17s, −28° 29.1′

Ceres sets by 11 p.m. local daylight time on the 15th.

2 Pallas (9.9) is moving southeast across the border between Serpens Caput and southern Hercules. Its positions:

1st: 15h 54m 21s, 14° 13.6′
10th: 16h 02m 28s, 12° 42.9′
20th: 16h 12m 29s, 11° 07.3′
30th: 16h 23m 28s, 9° 38.3′

Though Pallas lies west of Ceres, Pallas' higher declination keeps it visible until around 1 a.m. local daylight time on the 15th.

3 Juno (8.4) is moving east in Gemini about 10° south of Pollux. Its positions:

1st: 21h 51m 53s, −5° 31.6′
10th: 21h 45m 20s, −7° 07.2′
20th: 21h 39m 41s, −8° 48.9′
30th: 21h 36m 28s, −10° 18.6′

Vesta rises about 2:30 a.m. local daylight time on the 15th.

4 Vesta (8.4) lies in south-central Aquarius and is moving south-southwest. Its positions:

1st: 7h 09m 51s, 20° 49.4′
10th: 7h 24m 00s, 20° 32.9′
20th: 7h 38m 59s, 20° 11.6′
30th: 7h 53m 03s, 19° 48.5′

Juno sets around 4 a.m. local daylight time at mid-month.

39 Laetitia (10.2) is moving retrograde near the junction of Aquarius, Pisces, and Cetus; it is at opposition on September 21. Its positions:

1st: 0h 07m 53s, −3° 40.8′
10th: 0h 02m 40s, −5° 08.2′
20th: 23h 55m 57s, −6° 43.0′
30th: 23h 49m 03s, −8° 13.6′

Laetitia is visible all night.

To locate a minor planet, plot its dated positions (given for 0h UT) lightly in pencil on a good star map (*Sky Atlas 2000.0* or *Uranometria 2000.0*, for example) and sketch a smooth curve linking the points. Then observe the starfield at low magnification and photograph or plot by hand what you see. Check the field a night or two later; the "star" that moved is the minor planet. (All minor planet coordinates are for the epoch 2000.0.)

Jupiter

Though Jupiter rises in the east at the end of astronomical twilight, the best views will come when Jupiter is highest in the sky. This occurs around 3 a.m. to 4 a.m., so you may wish to schedule your Jupiter-watching for the wee hours.

Jupiter's apparent size is steadily growing, although the effect, naturally, isn't visible even from one week to the next. Yet if you compare the Planetary Data drawing of Jupiter for this month with that of

Jim Egger's photo of the Orion Nebula nets this month's $100 "Best Astrophoto" award. Egger used a 16-inch f/4.5 Newtonian, Ektachrome 400 film, and a 45-minute exposure. He then copied the negative onto Eastman 5071 recording film to increase contrast.

May, you'll see how much it has changed. Maximum apparent size comes at opposition on October 18.

In the second half of September a low-power eyepiece will show Jupiter moving steadily west toward 4.3-magnitude Omicron (ο) Piscium. On the 25th, Jupiter passes about 4′ north of the star. While Jupiter lies close to Omicron Piscium, the star will resemble a fifth "Galilean moon" that has somehow strayed from Jupiter's equatorial region.

Saturn

Although Saturn is now past prime viewing for the year, its location in the southwestern sky makes Saturn easy to observe during the first part of the evening. (Saturn sets well before midnight.)

In late summer and early fall this year the positions of Saturn, the Sun, and Earth produce an effect that gives Saturn a three-dimensional appearance in a telescope. Most of the year the light falling on Saturn and its rings is flat and frontal, so the shadow of the planet lies almost directly behind the illuminated disk. The whole thing looks like a floodlit piece of cardboard.

Now, however, our viewpoint is slightly away from the direct Sun-Saturn line of illumination, and thus we can catch a glimpse of Saturn's shadow falling across the rings. Some evening use medium to high magnification and look at the northeastern limb of the planet. (You may find the effect easier to observe in twilight before the sky is fully dark.) Can you see Saturn "in the round"?

Uranus

Slightly past the meridian as twilight ends, Uranus now offers the easiest viewing. Locate Uranus with the finder chart in the January 1987 issue, or scan 2-1/2° northeast from Theta (θ) Ophiuchi, a 3rd-magnitude star an hour of right ascension east of Antares. At 5.6 magnitude Uranus' disk measures 3.7″ across; bright greenish blue in color, it looks clearly nonstellar with moderate magnification.

Neptune

To find Neptune in the evening sky, center your scope on magnitude 2.8 Lambda (λ) Sagittarii, the star at the top of the Teapot's lid. Then sweep north 3° and west 1°. Neptune is at magnitude 7.9 and has a grayish disk 2.2″ across. It takes at least medium magnification to make the disk appear nonstellar.

Pluto

Pluto is too close to the Sun to be viewed in September.

If all you want is a low price, any camera or sporting goods store clerk can help you.

But . . .

if you need some advice before buying, you may find that they don't know their Maksutov-Cassegrain from a hole in the ground and think that eye relief is a new kind of Visine®. *And* you may have to wait months for your telescope (since fifty expensive cameras take up the same space as a single telescope, some camera stores refuse to keep an inventory of scopes in their high rent New York warehouses -- they'd rather cash your check before they even bother to *order* your scope). *And* you may not get all the parts you expect (scopes have been known to arrive with no-name Kellner eyepieces substituted for name-brand Plossls, 6 x 30mm finders substituted for illuminated 8 x 50mm polar finders, parts missing totally, etc.) *And* you may find that the fine-print freight charges are a lot higher than you expected (as much as $75 in the case of an 8" scope from one New York camera store).

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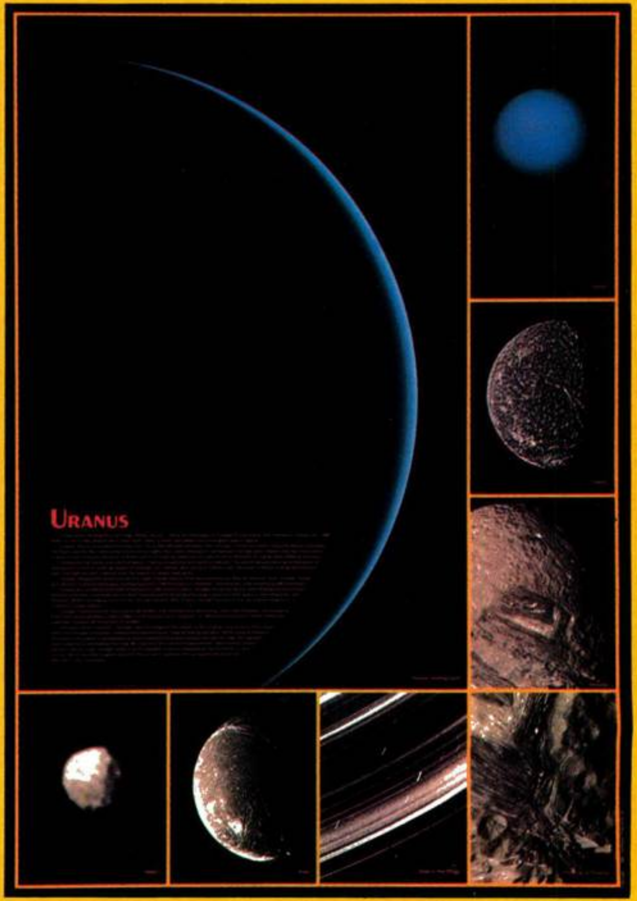

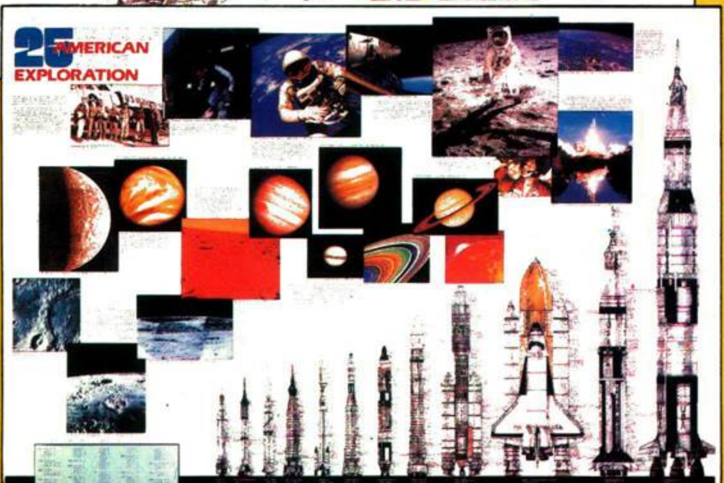

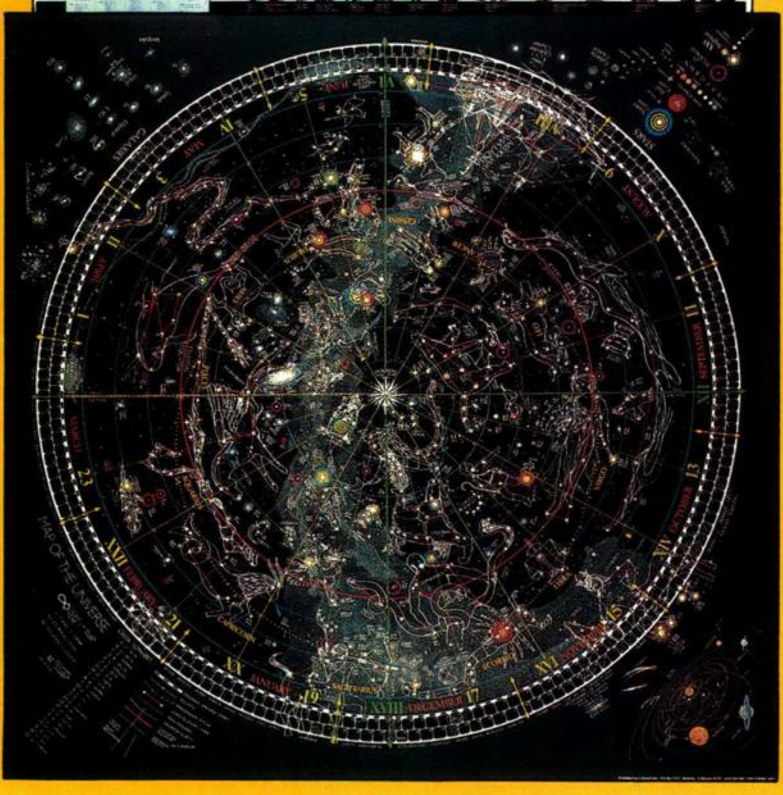

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